Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 222 JULY, 1936 No. 1

REPORT ON THE WORK OF THE BARTOL RESEARCH FOUNDATION, 1934–1935.*

MADE TO THE MEMBERSHIP OF THE FRANKLIN INSTITUTE.

BY

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I always feel that it is a little difficult to start these reports. I feel something like the small child, who, when asked to play certain portions in the middle of her piece is unable to do so without going back to the beginning and playing the whole thing through until she arrives at the place where she has been asked to play.

Our activities during the last year have centered around investigations concerning cosmic rays, and I propose to try and trace the course of these investigations for you by grouping them around the general story of the nature of the cosmic rays, and in particular around certain views as to the nature and properties of the rays which I have been led to formulate as the result of our own experiments and those of other investigators.

While I do not intend to follow the exact procedure of the small child, just cited, by going right back to the beginning of my piece, and starting a lecture on cosmic rays, I must go back a little way, at least, for the purpose of re-introducing

* Presented at the Stated Meeting held on April 17, 1935.

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to you some of the essential elements of the field whose development constitutes the main story of what I have to say.

I must remind you that, as a result of the developments of the last fifteen years or so, we have come to realize that our atmosphere and earth are being bombarded by rays of enormous energy and penetrating power, each of these rays having an energy a thousand, or even ten thousand or more times as great as the energy of the highest energy rays we have ever encountered from natural or artificially created sources in our laboratories. The most penetrating rays with which we are acquainted from natural sources are those emitted from radioactive materials. Thus, we have the so-called beta rays, which are electrons emitted from radium in its spontaneous disintegration. They have such an energy that a million or more volts would be necessary to give them that energy. The energy of the rays necessary to initiate the activities of cosmic rays is such that, if those rays are to be regarded as electrons, as much as ten thousand million volts would be necessary to give them the energy necessary.

One of the most fundamental questions before us is that which concerns the nature of the primary rays entering our atmosphere. The decision as to their nature is complicated considerably by the fact that when they strike the molecules of our air, they eject from those molecules other rays, secondary rays, as they are called, which also possess very great energy—energy far greater than that of any ray which can be produced in our laboratory apparatus either by devices of our own construction, or from radioactive materials. These secondary rays are, at any rate in large part, positively and negatively charged electrons. They are the things which produce in large measure the actual phenomena which constitute, in our apparatus, the subject of our measurements. They carry with them a story which is enormously interesting in itself, and related in an important way to the fundamental atomic processes involved in their creation. However, the starting point in the orientation of our thoughts toward a consistent understanding of everything which occurs is naturally an attack upon the question of what constitutes the primary radiation.

THE NATURE OF THE PRIMARY COSMIC RADIATION.

When the physicist encounters some new entity such as the cosmic ray, he likes to visualize that entity as one of the members of the family of physical entities with which he is already familiar. When he encounters a thing like a cosmic ray, he likes to say, "This is simply an electron: but since all the electrons I have encountered before can penetrate only a millimeter or two of lead, and this ray will go through seventy-five feet of lead, it must be an electron endowed with very great energy." Or he likes to say, "This cosmic ray is an x-ray; but, since all of the x-rays which we have encountered before are capable of passing through only a millimeter or so of lead, this x-ray must be an especially hard x-ray, one endowed possibly with an extraordinarily large amount of energy." In other words, the physicist does not like ghosts—he likes to feel that new agencies in the production of physical activities are new only in appearance. Fundamentally he likes to recognize them as his old friends. Physicists are very snooty about admitting any new entities into the realm of their activities. For years and years they excluded everything but the electron and the proton. Then after this old guard had exerted itself fruitfully for many years, had accomplished much marvellous work, and had arrived at a sort of stage of senility in which it looked as though it could not do very much more, there were found hanging around the portals of the holy of holy of physics, certain new interlopers clamoring to get in. They were, first, the neutron, and then the positive electron. These new arrivals are now busy seeking a place for themselves in the architecture of the atom. The electron and the proton will have to give up many of the things they had hoped to do single-handed in days gone by. The state of alarm in the atom is intensified by the expectation that at any moment there may arrive the negative proton, whose existence has, as it were, been threatened by the arrival of the positive electron. Now all of these things present themselves as candidates for the position of primary cosmic rays; and in addition, if we are to believe the Abbé Lemaitre, that our whole galaxy and all the spiral nebulæ outside were once congregated in a huge mass which blew up, emitting into space the whole solar system, comets,

meteors, asteroids, dust, atoms, and everything—if we are to believe this, we may see as candidates for the primary cosmic ray not only positive and negative electrons, protons and neutrons, but atoms of every kind, some of which have charges, and some of which are neutral. In other words the cosmic radiation would simply be the dust of that primeval explosion.

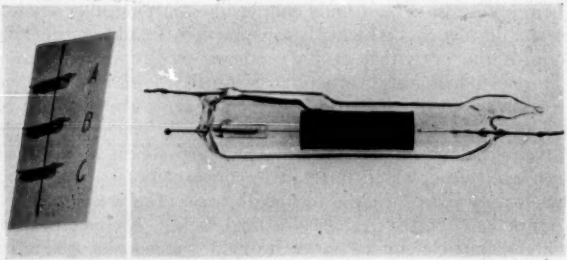
When the physicist has to decide between the various candidates for such a position as that of the cosmic rays, it is by the properties of these candidates that he must make the decision. He is in the position of one who, viewing a great jagged breach in a wall, hears somebody say, "That breach was caused by a bullet." "No," he must reply, "a bullet could never have made such a breach as that. Such a hole must have been caused by a slowly moving body of large size. It must have been an elephant that produced that hole." Or he is like one who, viewing a window with a round, clean-cut hole in it, hears someone say, "A fellow poked his walking stick through the window." He feels that he must reply, "No. A walking stick would have shattered the glass all over. Such a clean-cut hole as that must have been produced by a small thing traveling with a very high velocity, a thing like a bullet." Now our studies of electrons, neutrons, and hard x-rays, which last-named entities, in company with all wave-like entities such as light, gamma rays, etc., we have come to call photons, have taught us, in a general way, the nature of their properties. It is perhaps a rather wide extrapolation from the regions of energy in which we have become acquainted with those properties to energies ten thousand times as large, but such is the extrapolation which we must make in order to decide what we may expect of these entities when they travel in the guise of cosmic rays. Nevertheless, the physicist is sufficiently confident about many aspects of his theories to make this extrapolation much less drastic than might at first appear. And so we have come to look upon a charged particle, such as an electron, as characterized by the fact that in traveling through the atmosphere, it breaks up the outer structures of the molecules all along its path. It works continually. In each centimeter of its path at atmospheric pressure it produces about thirty pairs

of ions—broken molecules if you will—and expends the equivalent of about a thousand volts of its energy in so doing. Then when its energy is expended it comes to a dead stop. There is no gradual petering out of its activity. It works hard until the very end. As a matter of fact, in the last meter or so of its path it works hardest of all, like an old man going out on a party just before the arrival of the undertaker. On the other hand, photons, which comprise in their membership wave-like entities, of which the most familiar representative is ordinary light, and less familiar ones, ultraviolet light, x-rays, and gamma rays from radium—these photons act in a different manner in ploughing through the air. On relatively rare occasions do they do anything at all; and then they act quite drastically by hurling an electron, or perhaps even sometimes many electrons, out of an atom with great speed, leaving the plebeian work of ionization, the continual breaking up of atoms along the path of the entity, to the electrons which are ejected. In such an act the photon may entirely disappear, or it may change itself into another photon of smaller energy, which photon proceeds in like manner to imitate the activities of its predecessor. In other words, photons act mainly through assistants. Neutrons behave to some extent like photons. In a crude sense one may regard a neutron as a positively and a negatively charged particle traveling along in company. They are so much engaged with each other as to have little concern for the things by which they pass. In the technical mode of expression, they do not have an external electrical field. An electron or charged particle, by virtue of its field, extends its sphere of influence to a considerable distance. In passing through the gas it tickles the molecules all around it, and persuades several of them to break up and eject other electrons; but the members of the neutron pair travel along oblivious of everything until by their very concentration on each other they occasionally dive headlong into the heart of some atom. In such a case they become, as it were, very angry, and use all of their pent-up efforts in blowing up the atoms. The debris of this atom then goes about ravaging the outer structures of other atoms and producing that phenomenon which we call ionization. Thus neutrons, like photons, act,

as it were, through assistants. The main candidates for the position of the primary cosmic radiation are neutrons, charged particles and photons. Now what are the outstanding features which any theory as to the nature of the primary radiation must have? The first thing is concerned with what the physicist calls the exponential law of absorption.

The Exponential Law of Absorption.—I must remind you that we have methods of measuring what we call the intensity of the rays coming in any given direction. In my former reports I have dealt at some length with the use of Geiger-Mueller counters for this purpose, and many of our activities have been devoted in the past to the development and improvement of these devices. I must not at this time go into the details of this matter again. It must suffice to say that the Geiger-Mueller counter comprises a little metal tube, Fig. 1, with a wire passing down the center, everything being

FIG. 1.



enclosed in an outer tube containing gas at reduced pressure. With such a device and suitable batteries and recording systems, it is possible to cause the device to make a record every time a cosmic ray passes through the little metal tube; and, by having three of these in line as shown in Fig. 1, it is possible to arrange that the device as a whole will make a record, ring a bell, for example, or work any other recording mechanism when, and only when, a cosmic ray passes through all of the three metal cylinders. Under these conditions, the device acts as a sort of cosmic ray telescope and is capable

of giving us relative values of the number of rays which come to us from space in the general direction defined, for example, by AC, Fig. 1, and within the limits of angle determined by the dimensions of the cylinders A and C. For a given device of standard dimensions, we may take this property as representative of the intensity of the cosmic radiation for the direction AC.[1]

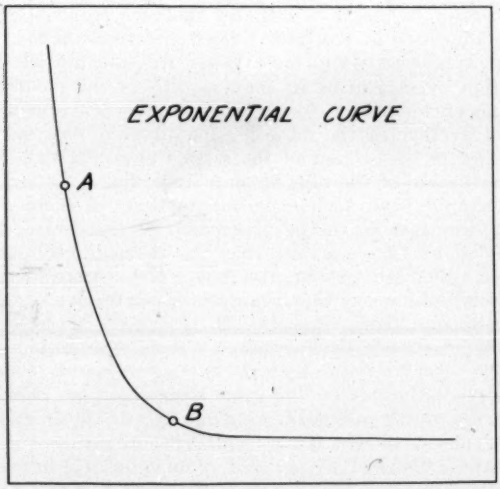
It is convenient to think of the atmosphere as compressed to a liquid of uniform density, and to speak of the variation of intensity of the rays with the distance traveled through this compressed atmosphere. Such an atmosphere is called a homogeneous atmosphere. When we measure the cosmic radiation by measuring its influence in causing conductivity in a gas enclosed in a closed vessel, we are concerned with a sort of average of the intensity for all directions; and it is necessary to dissect out of the results obtained the story of the absorption of the rays along a single line. So far, it has been mainly from such experiments that we have derived our information as to the absorption of these rays, and it turns out, as I have stated, that the absorption obeys what I have called an exponential law. Represented diagrammatically, this means that if we plot the intensity of the rays vertically and the distance which they have traveled, horizontally, the curve obtained is such as is represented in Fig. 2. The characteristic feature of this curve is that the intensity diminishes by the same percentage per centimeter of journey at all points of the journey. If the intensity at A is I_A, and of that at B is I_B, and if the intensity of the rays diminishes a tenth of one per cent. of its value at A in traveling a certain distance in the vicinity of the point A, it will diminish a tenth of one per cent. of the value at B in traveling the same distance in the vicinity of the point B. While it is true that the law of absorption is not absolutely exponential in the strict sense, it turns out that 90 per cent. of the radiation can be

[1] Physicists will recall that, if I is the intensity of the rays for the direction concerned, as measured by the number crossing unit area per second, and coming from within unit solid angle whose axis is parallel to the assigned direction, then the number of counts made per second by the telescope is N, where $N = Ia^2/L^2$, and where a is the cross-sectional area of the counter, and L the distances between the extreme counters.

accounted for by an exponential law and the remainder can be accounted for by a limited number of other contributions of the exponential type with different coefficients of absorption as they are called.[2] To a close approximation, the law is of the exponential type.

Now an exponential law is very naturally accounted for on the basis of the assumption that the cosmic rays are

FIG. 2.



composed of photons. To shoot a lot of photons into an atmosphere populated with atoms and molecules is like shooting a lot of bullets into a forest populated with trees. Some of the bullets will strike trees before they have gone more than a yard or two. Others will miss many trees and

[2] A word of caution must here be uttered against assuming too readily that the law of intensity as deduced from ionization measurements is necessarily the same as that deduced from counter data. In fact, such an assumption is probably only a rough approximation to the truth. This matter will be discussed more fully in a later part of the report.

go a great distance. If a machine gun should fire a stream of such bullets, all in one direction, the fraction of the bullets which would pass in one second through a square foot held perpendicular to the direction of their flight would diminish as the distance from the machine gun increased because the chance that the bullets would go any particular distance would decrease the greater that distance. The number passing our square foot at any particular distance would be determined entirely by the laws of chance. But, apart from the resistance of the air, which we are neglecting, and the fall of the bullets under gravity, which we are also neglecting, the bullets which had traveled half a mile would hit anything just as hard as the bullets which had traveled only one yard. The potency of the bullets to do damage would not be altered by the distance which they had traveled. As a matter of fact, if, on the basis of the law of chance, we should work out the theory of decrease in number of bullets per square foot with distance from the machine gun, we should find that it obeys just that law which we have referred to as an exponential law, and which is represented in its general characteristics in Fig. 2. Since the photons do not suffer any change until they hit an atom or molecule in such a way as to precipitate a drastic catastrophe, they are like the bullets in our analogy and the atoms are like the trees. An exponential law of intensity, or, if you will, of absorption, follows for them, therefore, very naturally. You will see that the characteristic feature which provides for a law of this kind is that the entity concerned, the photon or the bullet, loses practically none of its energy in passing through the medium, the atmosphere or the forest, as the case may be, except on rare occasions, and then it loses the whole of it. If instead of losing the whole of it, it lost a very large portion of it after one of these catastrophes, the law of absorption would approximate to an exponential law.

On the other hand, when we consider the possibilities of electrons as the primary cosmic rays, we encounter great difficulty, at first sight, in seeing how the exponential law can be accounted for. We must no longer take our analogy of the forest, and of bullets fired through it in such a manner

that only occasionally do they hit trees, becoming completely imbedded when they do so. We must think rather of our bullets as being shot into a large piece of cheese. Now as they go through the cheese they lose energy continually and every bullet travels approximately the same distance. If we should imagine a shower of bullets falling vertically upon a piece of cheese, every bullet would travel practically the same distance in the cheese. Below that distance there would be no bullets, and above that distance the number of bullets which traveled through a square foot would be the same at all places. If instead of coming in vertically, the bullets should come in in all directions then, for any one direction there would be a certain depth below which none of the bullets would reach, and above that depth the number crossing a square foot would be independent of the depth. On account of the fact that the bullets come in in different directions, we would thus obtain a variation in the number of bullets crossing a square foot at different distances below the top of the cheese, but if we should confine ourselves to any one direction, the number crossing the square foot perpendicular to that direction would be absolutely independent of the depth below the surface of the cheese until a depth was reached where there was a sudden change in the intensity of flux of bullets to zero. This feature as you will see is characteristic of the state of affairs where the entity concerned, the bullet, loses energy continually—that is where it loses energy in little bits all the way along its path—where it works continually but never does anything very drastic—where in each stage of its progress it loses a little of its energy but never at any one act loses a large amount of it. This is the kind of thing which we would expect on the simplest view that the primary cosmic rays were electrons. We should get a law of absorption which departed about as far from the exponential law as it possibly could. However, it is still possible to save the exponential law, even in the case of electrons. For, if the electrons entering our atmosphere are not all of one energy, if, in fact, there is a wide distribution of energy among them, then, those of higher energy will travel farther than those of lower energy, and we shall obtain a variation of intensity along any given direction. Starting at the top of the atmos-

phere, we have a certain number of electrons passing per second through our imaginary cosmic-ray telescope pointed in some particular direction. As we move the telescope further down along the line of its direction the number gets less because some of the softer rays have been absorbed in the upper regions of the atmosphere. As we descend further the number gets less and less. It is possible for us to think of the number of rays having different energies as being adjusted in such a way that, as the initially lower energy ones are sifted out in passing through the upper regions of the atmosphere and the initially higher energy ones are sifted out at lower depths, the net result is just such as to produce this very simple and characteristic exponential law. It would be very strange had Nature conspired to give us such a distribution of electrons as to provide for such a simple result, with apparently no reason other than that of making things agreeable for the student of the subject.[3] Before pursuing these matters in further detail, however, it may be well to return to the experimental evidence to see to what extent we are compelled to invoke the assistance of positive or negative electrons as primaries at all in view of the fact that apparently photons would give us such a very simple interpretation of the variation of intensity with depth through the atmosphere.

It is not so very long since electrons or charged particles in general were regarded as practically ruled out of consideration as candidates for the position of an appreciable portion of the primary cosmic radiation. The reason depended upon the well-known fact that the paths of charged particles are deviated in a magnetic field. The earth is a great magnet, and while its magnetic intensity is relatively weak, it extends over very great distances, so that its effect in bending the paths of electron rays is very powerful. The smaller the energies of the rays, the more easily are the paths bent. Many years

[3] For the more sophisticated reader I may perhaps soften this argument to some extent by pointing out that all that would be necessary to secure the result would be an exponential distribution of numbers of rays with energy as they enter the atmosphere. Such a distribution is, of course, not a very unlikely one in line with the general mechanisms of physics which give rise so frequently to such a distribution in other fields of the subject.

ago, the Norwegian physicist, Carl Störmer suggested that the Aurora Borealis might be caused by electrons emitted, in this case, with great energy from the sun. The effect of the earth's magnetic field upon these electrons would be to cause them to move toward the polar regions. The smaller the energy the more would be the tendency of the electrons to enter the atmosphere near the poles; and, even to get the aurora to exhibit itself, on such a theory, at latitudes as low as that at which it is found, Störmer found that it was necessary to attribute to the electron energies a thousand times greater than any which had been encountered in the laboratory at that time, and in those days such an assumption was regarded as very speculative. The mathematics of this subject is contained in its essential elements in the work of Störmer, done some twenty years ago. However, the subject has received a renewed interest in the light of modern developments in connection with cosmic rays. It has been convenient to consider certain specific matters sometimes as generalizations of, and sometimes as special cases of Störmer's theory, and sometimes by special calculations made *ab initio*, with the immediate end in view. Ten years ago I showed by calculation that an electron with an energy so large that a thousand million volts would be necessary to give it that energy, would not be able to approach the earth in its equatorial plane nearer than to eight times the earth's radius, without being turned back into space. To reach the earth's surface at the equator, an electron must have an energy at least the equivalent of that attained under a potential difference of ten thousand million volts. Even under these conditions, as I pointed out about three years ago, the electron which just succeeds in reaching the earth at the point A, Fig. 3, by describing an orbit in the magnetic equatorial plane, does so by describing a complete loop. It is easy to see why the electron describes such a loop. You might think that an electron coming from the lower half of the diagram and approaching the earth, would try to reach it at some point such as B. However as the electron approaches the earth, the earth's magnetic field demands that the path of the electron shall bend, and continue to bend. In order to be able to obey the earth's magnetic field and yet reach the earth, the electron describes the orbit $PCACQ$ shown in

FIG. 3.

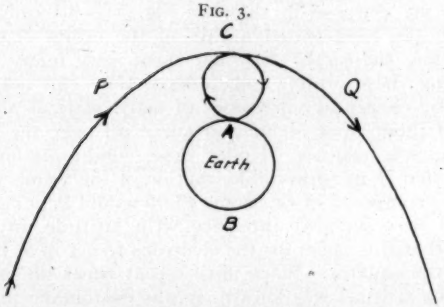
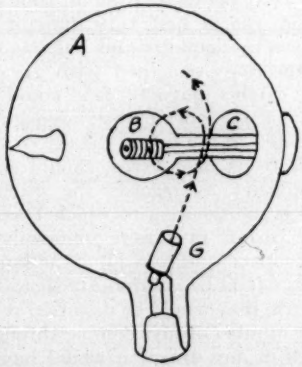


Fig. 3. By looping the loop completely, it is able to secure the maximum amount of bending in obedience to the earth's magnetic field and indeed actually makes use of it to come back and touch the surface of the earth before it returns to space.[4]

[4] Here was shown an experiment, in which *A*, Fig. 4, is a partially evacuated globe containing neon. *B* is a small glass sphere connected to the tube *BC*.

FIG. 4.



Through *BC* into *B* is thrust a solenoid containing a piece of iron which can be magnetized. An electron gun at *G* shoots out a beam of electrons which by excitation of the solenoid were caused to emulate the loop of Fig. 3, and various other orbits.

Now my purpose in showing Fig. 3 is to call to your attention the complicated nature of the orbits of electrons approaching the earth. Störmer spent very many years in calculating these orbits; and, indeed, they can not be calculated by elementary processes of mathematical procedure. Many of them twist about and curve all over the place in most fantastic manner. Under these conditions one might suppose that if an appreciable fraction of the primary cosmic rays were composed of electrons, there would be a very great variation of cosmic-ray intensity with latitude, in view of the fact that it is easier for the electrons to get in at the poles than at the equator. Since until recent times no such variation with latitude was known, it was customary to assume that no appreciable fraction of the primary rays could consist of charged particles. Then three or four years ago, J. Clay in Europe and A. H. Compton and his associates, in a world survey, found a definite variation with latitude, but of a rather peculiar nature. For latitudes north or south of 34°, there was very little variation. For latitudes lower than 34°, there was a diminution in cosmic-ray intensity which amounted to 14 per cent. of the equatorial value at sea level and to as much as 33 per cent. at an altitude of 4,300 meters. Such a condition was at first very difficult to understand. Then it was shown by Lemaitre and Vallarta that if a certain mathematical theorem concerned with the motion of the electrons in the earth's magnetic field could be regarded as true, the story of the cosmic-ray intensity, although extremely complicated in the actual details concerned with the orbits of the electrons themselves, should show remarkable features of simplicity as regards the intensity itself. It turned out that if the theorem to which I have referred was true and if the cosmic rays were uniformly distributed in direction in outer space, and were all of the same energy, then, while their paths would be enormously distorted as they approached the earth, they would be distorted relatively to each other so that the number of rays coming through a cosmic-ray telescope pointed in any direction would have the following characteristics. At any assigned place, *either* the number would be exactly the same as it would have been had there been no magnetic field, in spite of the fact that the direction of

these rays if produced backwards outside of the earth's atmosphere to remote distances would there have nothing like the directions which they would have had in the absence of the earth's magnetic field, *or* the number would be zero. There could be no compromise. Either the electrons would come in with the normal intensity or they would not come in at all. The truth of the mathematical theorem to which I have referred was first sensed by Lemaitre and Vallarta. It was found subsequently to involve principles rather more subtle than had first been supposed, but later by a more rigorous mathematical treatment of the subject I was able to establish the truth of the theorem in a manner which I believe is regarded as satisfactory even by those who have doubts concerning the complete story of the Lemaitre-Vallarta theory itself. The significant elements of the Lemaitre-Vallarta theory may be illustrated in the following way. Suppose that we confine our attention to electrons of any one energy, and let us say of positive sign. Then, in general, if we should take our stand at any particular latitude on the surface of the earth, there would be for any assigned electron energy, a certain cone with its axis of symmetry tangential to the earth and pointing due west, and such that within this cone, no rays of the assigned energy would enter. Outside of it, the rays would enter with the normal intensity. As we moved towards the pole, the cone would become narrower in angle, and at some latitude sufficiently high would become so narrow as to close up completely, so that, at this latitude, there would be no direction from which rays of the assigned energy could not enter, and the same may be said for all higher latitudes.[5] Going back to our starting point, however, and moving towards the equator the cone would widen up in angle so that the direction from which rays could not approach would comprise more and more of the sky. If the assigned energy of the electrons were sufficiently small, the cone would widen up to such an extent as to turn inside out and cover the whole of the sky. Under these conditions no rays of the energy concerned would reach the point in question from any direc-

[5] At this point, the properties of the cone at different latitudes were illustrated by a large globe and a sort of umbrella which could be opened up to different extents to illustrate the variations of the angle of the cone with latitude.

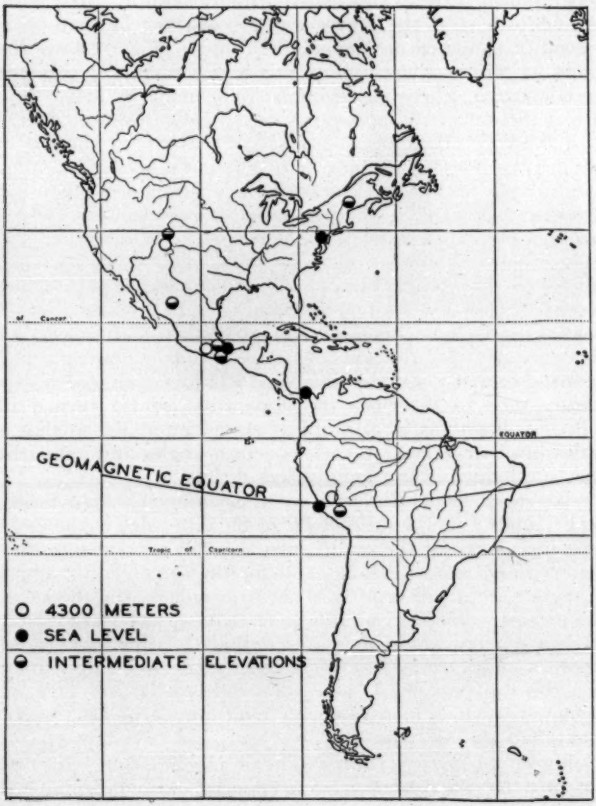
tion whatsoever. On the other hand, if the energy were sufficiently high, the cone of exclusion would narrow down to a small angle, even to zero angle at the equator itself, so that here and everywhere else on the earth, rays of this energy would enter from all directions.

This story of the cone contains the story of the total cosmic-ray intensity with latitude, and it also contains the story of the difference between the intensity from the east and from the west for any given latitude. If all the rays had one single energy and all carried the same sign of charge, the story of the difference between the intensity from the east and from the west would be very simple. If we were at a place where the cone of exclusion existed at all, there would be no intensity from the east and the full intensity from the west. In general, this story is complicated by the existence of a wide range of energies for some of which there is an exclusion angle and for some of which there is not. It is also complicated by the possibility of there being charged particles of both sign. It is obvious that if charged particles of both signs existed in equal amounts there would be no difference in intensity from the east and from the west, although there would, of course, be a reduction in each of these intensities. The whole story of these latitude and directional effects is rather complicated, and I must not enter into it in detail.

Investigations upon Directional Phenomena.—The directional effect has been the chief subject of Dr. T. H. Johnson's interests during the last two or three years. In collaboration with Dr. J. C. Street, who was with us at the time, he found the first indications of a directional effect in the summer of 1932. The nature of the effect was such as to indicate that there was a preponderance of positively charged particles in the cosmic radiation. Following this, Dr. Johnson, and almost simultaneously Dr. Alvarez working as Professor A. H. Compton's assistant in Mexico, found very definite east-west effects. Later Dr. Johnson extended these observations to various latitudes and altitudes. Of much of this work I have spoken in my former reports. The stations at which directional measurements have been made are shown in Fig. 5.

Since my last report, Dr. Johnson has made a series of investigations at Mount Evans, in Colorado, and at Copilco,

FIG. 5.


of Cancer
EQUATOR
GEOMAGNETIC EQUATOR
Tropic of Capricorn
4300 METERS
SEA LEVEL
INTERMEDIATE ELEVATIONS

Nevado de Toluca, Vera Cruz, and Parral, in Mexico. It may be of interest to show some pictures illustrating the geographical features associated with this work. In Fig. 6, the white tent at the center was the working laboratory at 14,000 ft. elevation on Nevado de Toluca. Fig. 7 shows the camp at Mount Evans. Fig. 8 is a closer view of the tent at Huancayo, where observations were made in 1933. Fig. 9 is a picture of the apparatus used by Dr. Johnson in the 1934 survey. It comprises, in its essentials, a number of cosmic-ray telescopes pointed in different directions. Thus for example, as will be clear from the diagrammatic figure at the side of Fig. 9, A, B, C represent three counters [6] which together constitute a telescope pointing in the direction AC. DBF constitute another telescope and so on. When a cosmic ray passes through any one of these telescopes, a corresponding record is made by causing the hand of a dial to move on by one unit. There is a dial mechanism of this kind for each of the telescopes and the whole system of dials is photographed at intervals. By automatic mechanical processes which it is unnecessary to describe, the apparatus is also turned in different directions in azimuth at stated intervals, so that a series of observations at various zenith angles and azimuths can be obtained over a long period of time.

We may define the east-west asymmetry, A, for any zenith angle θ, as the ratio of $I_{a\theta}$, of the difference in the east-west intensities for the zenith angle θ to the average intensity $I_{0\theta}$ for those two directions, and for the same zenith angle. If there were no absorption in the atmosphere, the theory of the matter would lead us to expect that, at any given place, the asymmetry would increase continually with increase of zenith angle. On account of the increasing absorption towards the horizontal, however, the experiments give an asymmetry which increases with zenith angle up to a maximum, and then decreases.

Figure 10 gives a compilation of Dr. Johnson's results, obtained for the variation of asymmetry with latitude and

[6] As a matter of fact, each of the circles, A, B, C, represent three counters, each of which functions as a single counter. This arrangement, which is customary in all modern counter methods, has certain advantages which it is not necessary to describe here.

FIG. 6.

FIG. 7.

FIG. 8.

FIG. 9.

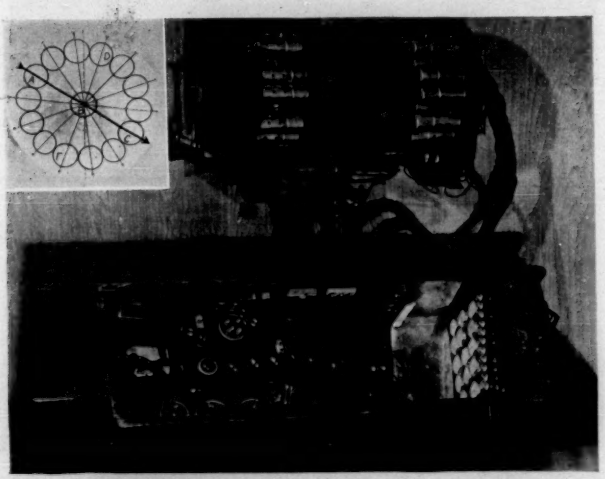
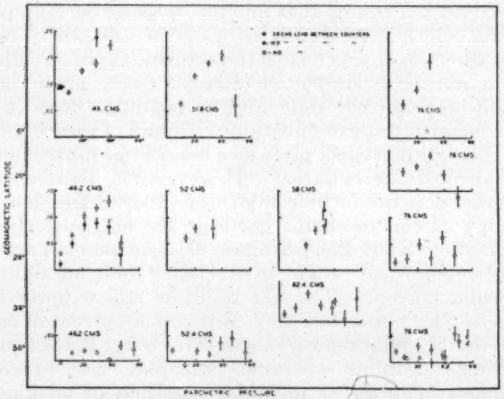


FIG. 10.



altitude on the various surveys. In each of the plots, the ordinates represent asymmetry and the abscissæ, zenith angles. The barometric pressure in centimeters of mercury, indicative of the altitude, is expressed in centimeters of mercury for each plot. The upper three plots are for the equator (latitude zero). The single plot next below, to the right, and corresponding to 76 cms. of mercury, is for 20° latitude. The next four below are for 29° latitude. The single one at 62.4 cms. of mercury, is for 36°, and the lowest three for 50°.

The general significance of these results and of the agreement with the corpuscular hypothesis, and with the Lemaitre-Vallarta theory has been referred to in former reports. The significant features are as follows:

1. The radiation of corpuscular nature which carries a positive charge is in excess of that carrying a negative charge.

2. By combining the latitude variation in intensity, which depends upon the sum of the negative and positive corpuscular currents, with data on asymmetry, which are determined by the difference between these currents, Dr. Johnson is able to determine how much of each sign of current

is involved. Confining attention to the sea level data on the latitude effect, it results that practically all of the corpuscular radiation which corresponds to energies sufficiently low to show a directional effect is of the positive type. While this result is not as inevitable when based solely upon the less accurate high altitude data for the latitude effect, it is in agreement with those data within the limits of their accuracy.

3. The latitude effect gives us a lower limit for the amount of the corpuscular radiation. However, the limit obtained in this way does not include any corpuscular radiation of such an energy as can reach the earth at the magnetic equator. On the other hand the existence of an asymmetry at the equator enables one to add to the lower limit an additional corpuscular current. The net result is still a lower limit, because it does not include any corpuscular current of energy so high that it would show no asymmetry effect at the equator. Proceeding according to these principles, and expressing percentages in terms of the total radiation of all kinds as measured at high latitudes, Dr. Johnson has been able to add 2 per cent. to the 12 per cent.[7] resulting from A. H. Compton's latitude measurements at sea level. This would lead us to conclude from the sea level observations alone that at least 16 per cent. of the intensity as measured at high latitudes is of the charged corpuscular nature. However, if we confine measurements to those at high altitudes, Dr. Johnson finds that the equatorial asymmetry data demand a minimum contribution of 6 per cent. to the high latitude, high altitude intensity; and A. H. Compton's latitude measurements give a contribution of at least 25 per cent.,[7] so that these high altitude measurements demand a total contribution of 31 per cent. as the minimum charged corpuscular contribution to the radiation.

It must be remarked that the 25 per cent. and the 16 per cent. cited above does not constitute a discrepancy. Both are lower limits, and the high altitude data give the larger value because they are more sensitive to the corpuscular phenomenon since they involve lower energy rays which have not been absorbed by the lower regions of the atmosphere.

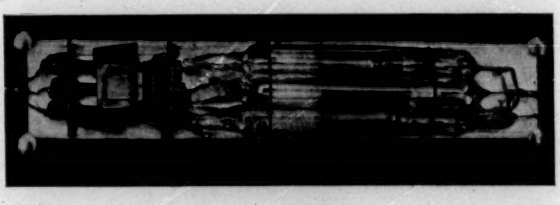
[7] The 14 per cent. quoted by Compton is expressed in terms of the intensity at the equator. A similar remark applies in the case of the 25 per cent. cited later, which corresponds to Compton's 33 per cent. of equatorial intensity.

Since my last report, Dr. Johnson has observed an effect concerned with a difference between the intensity from the north and from the south, an effect which is of more subtle nature than the east-west effect, but one which is included in the general story of the Lemaitre-Vallarta theory. He has also investigated the story of the production of showers of charged particles from lead by the rays from different azimuths, and has found that there is less asymmetry in the production of the showers than there is in the cosmic radiation itself. I shall presently have occasion to refer to an interpretation of some of these results in connection with their bearing upon the nature and properties of the primary cosmic radiation.

Cosmic-Ray Investigations in the Stratosphere.—At the time of my last report, Dr. Locher and I were busy designing apparatus for cosmic-ray measurements by means of Geiger counters, in the stratosphere. Since that time, two stratosphere flights have been made, the first by Major W. E. Kepner, Captain A. W. Stevens, and Captain O. A. Anderson, under the National Geographic Society and the U. S. Army Air Corps, and the second by Professor and Mrs. Jean Piccard. For both of these flights we designed apparatus which was carried and operated satisfactorily. As we all know, the first of these flights ended in a catastrophe from which, however, we were able to salvage a portion of our records and to deduce from them certain significant results. The second flight, that of the Piccards, was in every way successful. The apparatus was in perfect condition, and was, in fact, running, when the landing was made. In both of these flights the apparatus was installed in a dowmetal gondola which was suspended from the balloon. In the National Geographic flight the diameter of the gondola was 8 ft. 4 inches; and when it is realized that it contained apparatus for radio-broadcasting, for the measurement of spectroscopic intensity from the sky by two different instruments, six spheres for collecting air samples, three pieces of apparatus supplied by Professor Millikan for measuring cosmic-ray intensity by ionization in closed vessels (one of these electroscopes being surrounded by 600 lbs. of lead), apparatus for measuring the temperature of the air, three

barometers for measuring the pressure, supplies of liquid air, parachutes, ballast, air-conditioning equipment, apparatus for measuring the intensity of solar radiation, and three men to manage everything, it will be realized that our own apparatus had to be accommodated in rather crowded quarters.

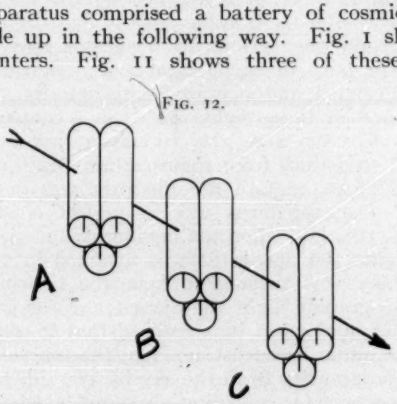
FIG. 11.



The Piccard gondola was even smaller, in fact 7 ft. in diameter, but naturally it did not carry so much equipment in addition to our own.

Our apparatus comprised a battery of cosmic-ray telescopes made up in the following way. Fig. 1 shows individual counters. Fig. 11 shows three of these bunched

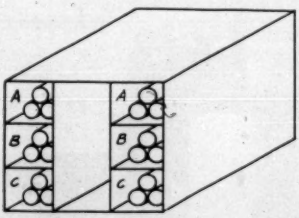
FIG. 12.



together so as to form the equivalent of a single counter element. Three such bunches, *A*, *B*, and *C*, Fig. 12, constituted a cosmic-ray telescope in the sense that a ray passing through all three will record itself on the recording mechanism.

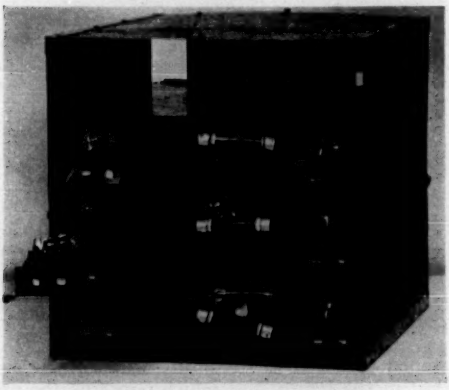
Fig. 13 shows two of these telescopes arranged side by side in a box which also contains the electrical equipment designed by Dr. Locher, and associated with the amplifying systems

FIG. 13.



which provide the necessary currents to feed the recording mechanism. By turning this box in the desired directions, relative values of the intensity in those directions can be

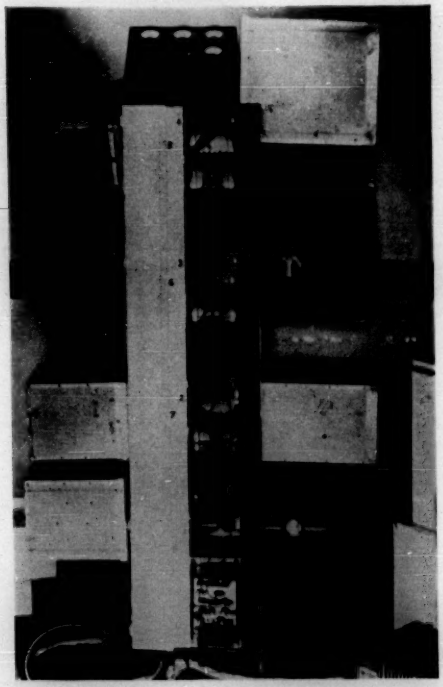
FIG. 14.



secured. Fig. 14 shows an actual picture of such a box with one of the counter units drawn out so that it can be seen. There were four such boxes, with the telescopes pointing

vertically in the first, 30° from the vertical in the second, 60° from the vertical in the third, and 90° from the vertical in the fourth. Fig. 15 shows, on the left-hand side, these four

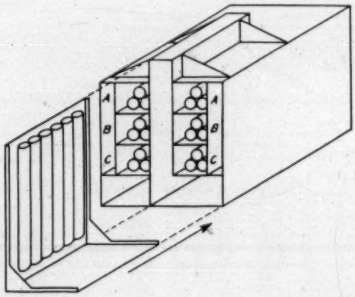
FIG. 15.



boxes fastened to a central structure which looks something like a pulpit in the figure, and which contains the meters for adjustment of currents and all the wiring systems leading from the batteries to the counters, and from the counters to the recorders. There were four other telescope units,

which are shown at the right of Fig. 15. They differ from those I have described in a manner, and for a reason which will now be explained. Reverting to Fig. 13, it will be seen that if a group of cosmic rays traveling along together in a direction inclined to the axis of one of the telescopes should send one of its members through *A*, another through *B*, and another through *C*, at practically the same instant, the telescope would be deceived into thinking that a single ray had gone through *A*, *B*, and *C*. For this reason we added, as shown diagrammatically in Fig. 16, an additional set of long

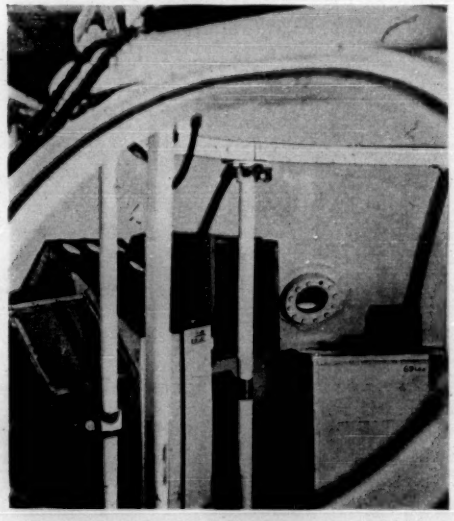
FIG. 16.



counters, shown vertically in the figure, and which in use were pushed in the direction of the arrow so as to fit into the slot provided between the two parallel telescopes. It will be observed that any ray which would form one of the groups to which I have referred as entering sideways would be unable to pass through *A*, *B*, or *C*, without passing through the long counters. No three rays could conspire to deceive the apparatus without each one of them passing through these shielding counters. The electrical system was then arranged so that any simultaneous discharge of the elements *A*, *B*, and *C*, of a telescope which was accompanied by another simultaneous discharge from the long counters would be annulled as regards the ultimate record. Thus these shielded counters were protected from spurious effects which I have

referred to. Corresponding to every unshielded telescopic unit shown to the left of Fig. 15, there was another shielded unit to the right. These shielded units are shown by the larger boxes in Fig. 15. By a comparison of the shielded and unshielded units it was possible not only to eliminate the spurious effects to which I have referred, but also to estimate their magnitude. The arrangement I have described is that used in the Piccard flight, and Fig. 17 shows another view of

FIG. 17.

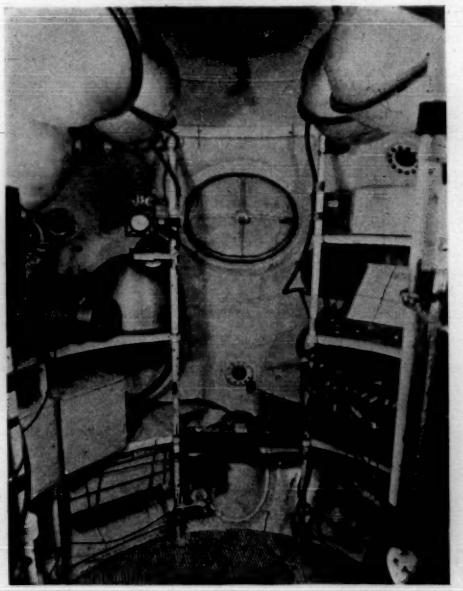


it. In the National Geographic flight the counter boxes were distributed around the shelves of the gondola, and were connected to a different kind of panel shown by the plugs attached to it in Fig. 18.

Each of the eight pairs of telescopes was made to record the number of cosmic-ray corpuscles going through it, in two independent manners. In one of these, a modified watch was

used in such a way that each count resulted in the passage of one tooth of a cog by the escapement lever. The markings on the faces of the watches were replaced by pin-heads and the dials were blackened. The whole assembly of watches was photographed upon moving photographic paper during

FIG. 18.

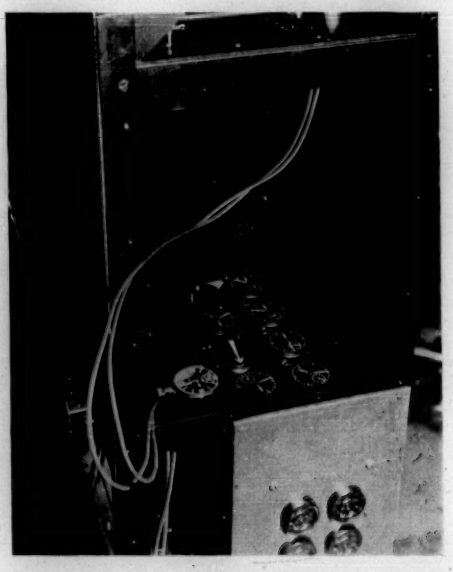


the observations, once every twenty seconds, in the National Geographic flight, and once every half minute in the Piccard flight. On the same record was obtained the photograph of the dial of a mariner's compass giving the azimuth of the gondola, and a picture of a real watch so that the time could be obtained, and consequently the altitude by a comparison with the pilot's log. Fig. 19 is a picture of the various re-

cording dials, of the watch, level indicator, and of the compass, shown by the large arrow.

A second method of recording was also utilized, and this differed in the two flights. In the first flight the method used was that illustrated in Fig. 20. *AB* is a solenoid carrying permanent current. It supports in space a piece of iron rod

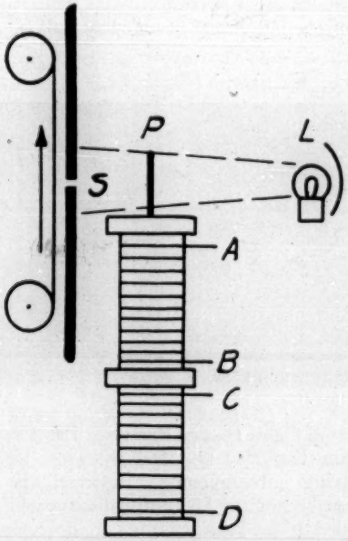
FIG. 19.



shown by the black line. The lower end of this rod dips into the end of another solenoid which becomes excited when it receives a pulse of current from one of the counter sets. The excitation of the lower solenoid results in a sudden dive of the iron rod. There was one of these solenoid systems to correspond to each of the eight counter systems. A beam of light falling upon the upper ends of the iron rods caused eight shadows of these rods to fall upon a horizontal slit behind

which photographic paper moved continuously in a vertical direction. In the absence of any pulses, the eight shadows showed as eight vertical white lines on the developed photographic paper. When a counter pulse occurred, the corresponding iron plunger dived down, permitting the momentary passage of light onto the slit, resulting in a black inter-

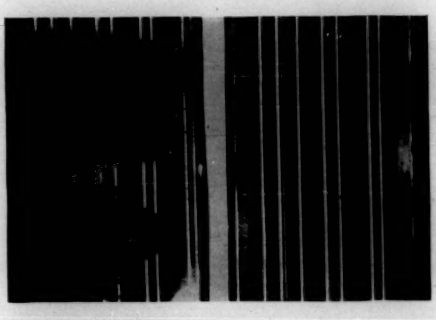
FIG. 20.



ruption of the corresponding white line, on development. In this manner each counter pulse was caused to record itself as an interruption of one of the white lines. This system makes it possible to observe simultaneous discharges of two or more telescopes due to "showers" of rays coming from cosmic-ray nuclear disintegrations, particularly those produced in the massive material contained in the gondola. The iron plungers moved with extreme rapidity, so that the system was

capable of counting a large number of rays per minute. As a matter of interest, I show Fig. 21, which represents two portions of the record salvaged from the National Geographic flight. The picture on the left represents a portion which was particularly badly fogged by the camera having been broken open. The portion on the right represents a piece in relatively good condition. The white lines crossing the record horizontally represent 20-second intervals. The short black lines shown crossing the vertical white lines represent the records of the individual cosmic-ray pulses.

FIG. 21.



In the second flight, that of Professor Piccard, the solenoid method of counting was replaced by what we may call a composite string galvanometer. Between the poles of a magnet were stretched ten fine vertical wires which, by means of a light placed at the back, cast ten shadows upon a camera slit behind which moved photographic paper in a vertical direction. The ten shadows made ten white traces upon the photographic paper. With each counter telescope system was associated one of the wires, which received a current pulse when that counter system discharged. The pulse caused a deflection of the wire, allowing light to pass to a place where there would otherwise have been a shadow, so that the vertical white lines became crossed with black ones indicating the individual pulses.

Since a very slight tilt in the vertical direction produces a change of cosmic-ray intensity of amount comparable with that produced by a considerable rotation in the horizontal direction, it was very necessary to keep the apparatus as horizontal as possible, or at any rate, to know how much it departed from the horizontal in the plane containing the axes of the telescopes. For this reason a sort of pendulum was constructed with a small electric lamp at the position of the bob. An image of the filament of this lamp traced a line upon the photographic paper; the departure of this line from a standard position gave the tilt of the gondola at any instant. In the Piccard flight a slight modification of the procedure was adopted.

The record containing the pictures of the recording dials and the level-indicator was completely lost from the National Geographic flight. In the Piccard flight, however, where, incidentally, all of the records were on one roll of paper, everything was preserved. Fig. 22 shows a picture of a piece of this record. To the left is a white line indicating the level record. Then come the recording dials, watch and compass dials. To the extreme right are the lines on which may be found the markings from the string galvanometer. They are not readily visible in the reproduced photograph shown in Fig. 22.

I may say that we are now busy preparing for another stratosphere flight under the auspices of the National Geographic Society and the U. S. Army Air Corps.[8] In this the cosmic-ray telescope system is practically the same as before, with the addition of two extra units, but we have greatly improved our recording mechanisms. Fig. 23 shows one of the dial recording systems in which, now, the motion of the pointer is caused directly by the motion of a plunger which is jerked down when a pulse from the corresponding counter discharge excites a solenoid surrounding it. This appliance

[8] Since this report was presented, the flight in question was attempted and failed on account of ripping of the balloon. The instruments were unharmed. At the time of writing this report the preparations for another attempt were under way. Now, as the report goes to press, the flight has been successfully made, and a fine set of observations has been obtained. The discussion of these must be reserved for next year's report.

FIG. 22.

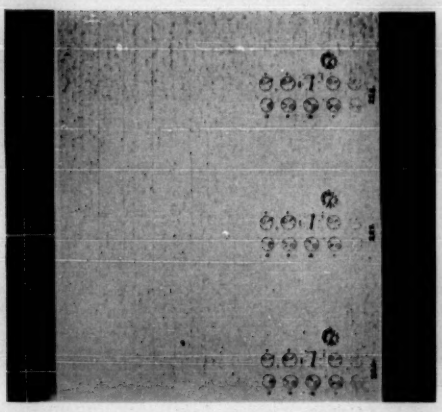
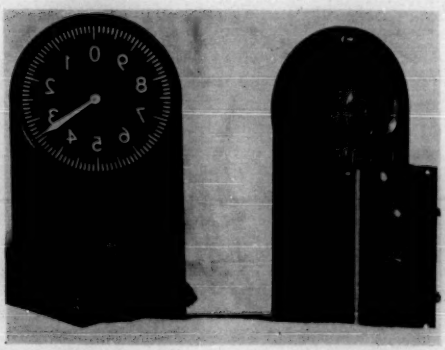


FIG. 23.



will operate satisfactorily up to 100 pulses per second. In the second method of recording we have reverted to the same principle as that which we used in the first National Geographic flight, but with certain improvements which, while fundamentally important, are not suitable for description here. Fig: 24 and Fig. 25 will be sufficiently clear from the

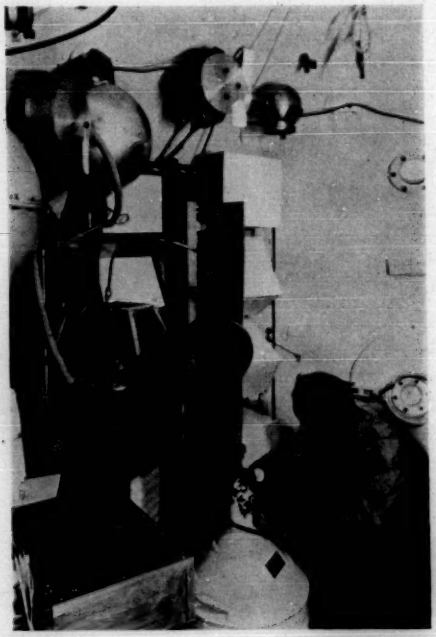
FIG. 24.

The picture shows Dr. G. L. Locher to the left and Mr. Oscar Steiner to the right. They are holding the recording unit for the counter telescopes. On the top to the left, is a special form of optical recorder. The camera is to the right. Below, is the box containing ten dial recorders, one compass, a watch and a level indicator.

legend attached. Figs. 26 and 27 give pictures of the apparatus as prepared for the new flight, and the significance of the various parts will be sufficiently clear from the legends attached. In addition, in this flight we are including an

apparatus for investigating the increase with altitude of those atomic bursts produced by the impact of cosmic rays with atoms of lead to which I have referred in my former reports. Essentially, this apparatus comprises a sphere of dowmetal

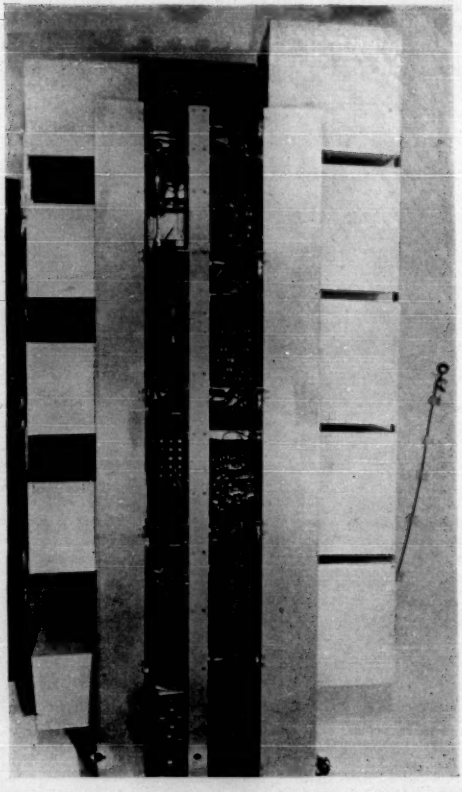
FIG. 25.



The picture shows Captain A. W. Stevens in the gondola. The cosmic ray telescope assembly shown in Fig. 26 is visible together with apparatus associated with other projects.

under a central insulating system connected to a suitable electroscope recording system. Forty pounds of lead are placed above this sphere. As the cosmic rays fall upon this lead they produce, occasionally, effects which are something

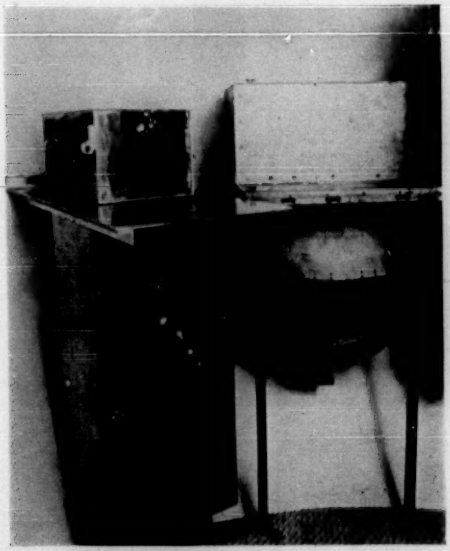
FIG. 26.



The picture shows ten white boxes, five to the left and five to the right. Each of these boxes contains 18 Geiger counters arranged in the form of a "telescope" for cosmic rays and the different boxes correspond to cosmic ray telescopes pointed towards different directions in the heavens. The central column contains the switchboard arrangements and control dials are at the top.

like explosions, in which showers of charged particles pass through the gas in the vessel, causing large spurts of ionization which give rise to certain movements in the electroscope system. In my former reports I have referred to the investigations which Dr. and Mrs. Montgomery and I have

FIG. 27.

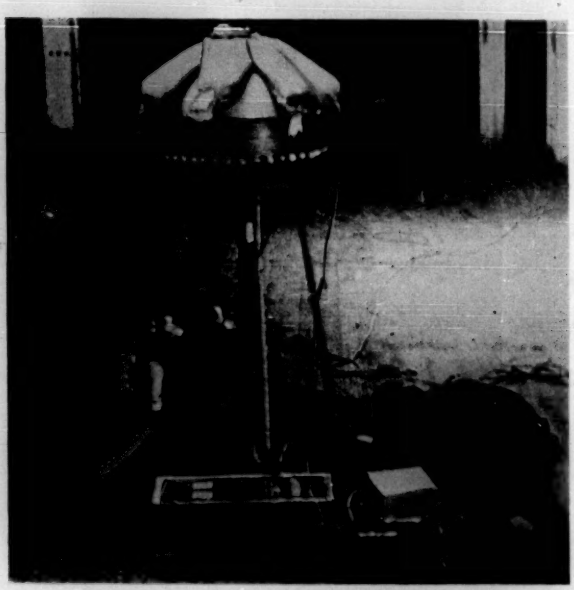


The picture shows to the left a portion of the recording unit and camera for the cosmic ray counters. To the right is a dow metal sphere, containing compressed nitrogen. Above the sphere is a slab of lead hardly visible. The cosmic rays explode some of the atoms in the lead. The debris of these atoms is shot into the sphere where it produces on each occasion a spurt of electrical conductivity which is made evident by the apparatus enclosed in the case in the back and recorded by two cameras not shown.

made of these Hoffmann stösse, as they are called. We prepared an apparatus to measure them in the first National Geographic flight, but, fortunately for the apparatus, there was not space to accommodate it. Then last summer, Dr. and Mrs. Montgomery, after improving the apparatus, took

it to the top of Pike's Peak, and measured the increase of the number of bursts per hour at that altitude. They found that while the cosmic-ray intensity itself increased by a factor of five from sea level to the summit of Pike's Peak, the number of bursts of all sizes increased by a factor of twenty-

FIG. 28.

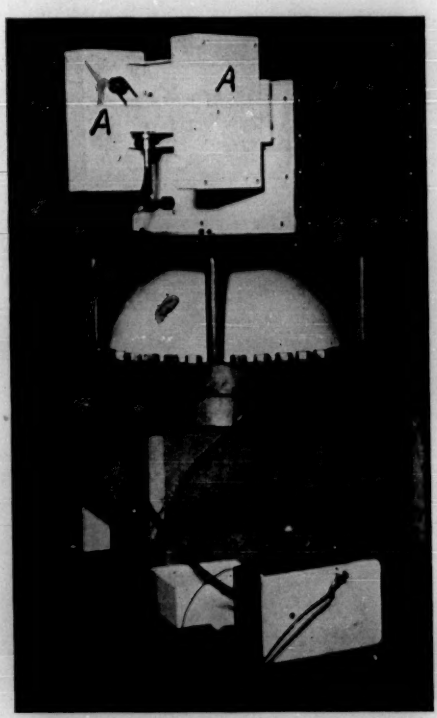


The large sphere shown is of dow metal. It is filled with nitrogen under pressure. The bags on the top contain the lead shot from which the atomic bursts are, for the main part, produced.

five. This fact has in my judgment a most profound bearing upon the nature of cosmic-ray phenomena, and has led me to formulate a new theory of cosmic-ray mechanism to which I shall presently refer. Fig. 28, shows a picture of the apparatus used by the Montgomerys at the top of Pike's

Peak. Fig. 29 is another picture of the apparatus which we designed for the most recent stratosphere flight. One of its

FIG. 29.

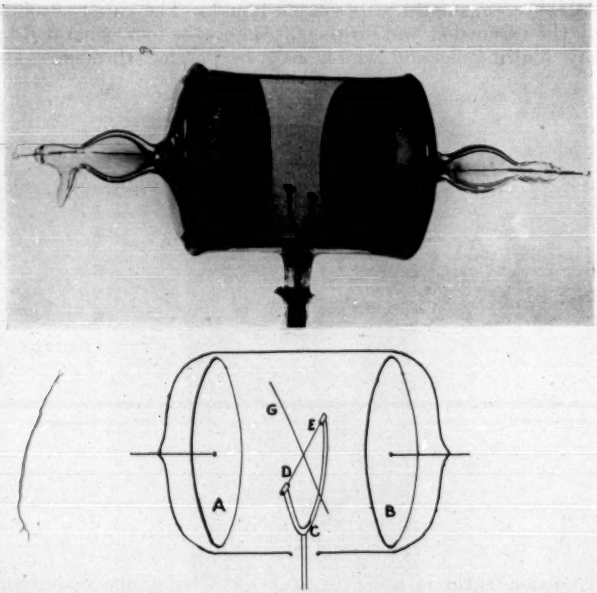


The dow metal sphere shown in Fig. 28 is again seen. On the top is a box containing the two electroscopes and the electrical system, together with an optical system which focuses the fibers of the electroscopes on motion picture film contained within the two cameras *A*. Between the cameras is seen the motor which drives the films.

chief features is the incorporation of the new type of electroscope which I have recently devised for the purpose of com-

bining ruggedness, stability, simplicity of construction, and high sensitivity. A picture of this electroscope is shown in Fig. 30, and the legend and sketch attached describes it. Two of these electroscopes designed for different sensitivities

FIG. 30.



The lower picture, which is diagrammatic, shows a fine platinized quartz fibre *D E*, mounted on a yoke. *G* is a slightly thicker quartz fibre whose upper half is platinized to a point just beyond its center. The center is soldered to *D E*. *A* and *B* are sheets of metal gauze which make contact with two thickly platinized rings on the glass case. The space between these rings is rendered conducting by a thin internal coat of platinum. The whole system is partly evacuated.

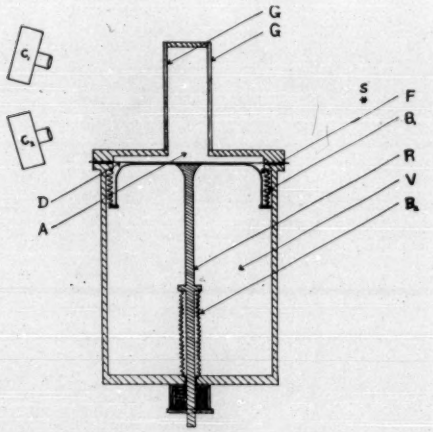
will be incorporated with the stoss apparatus, and will produce their records upon a moving 35-mm. film.

The large increase of Hoffmann stösse phenomena with altitude makes it of vital interest to examine, at high altitudes, the nature of the particles ejected in these atomic cataclysms.

The most effective method for this purpose is that involving the use of the well known cloud expansion apparatus.

It will be recalled that, in its essentials, a cloud expansion apparatus comprises a chamber whose volume can be caused to increase suddenly by the movement of a piston which forms one of its ends, usually its lower end. The chamber contains a gas and a vaporizable liquid. The vapor is cooled by the expansion and droplets form on the ions generated by any ionizing agency which may be passing through. The

FIG. 31.

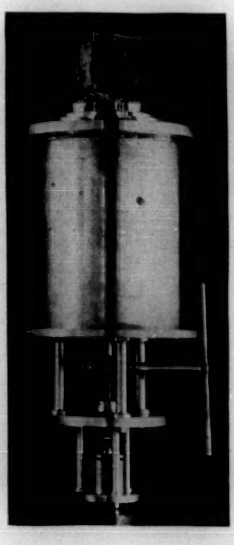


expansion ratio is quite critical for satisfactory operation. The piston motion is brought about by suddenly connecting one side of the piston to an evacuated chamber. The whole mechanism is rather heavy and complicated; and, for this reason, bearing in mind extension of the experiments to increasingly high altitudes, and finally to balloon measurements, Dr. G. L. Locher has devised certain modifications of the cloud expansion apparatus with these purposes in view.

The first of these pieces of apparatus is represented in Fig. 31. *A* is the expansion chamber which is separated from

a chamber V by a thin rubber diaphragm D which rests on a movable metal dome F. The vessel V is partially evacuated and the dome is held up in position by the rod R against the pressure of the gas in A. The wavy lines represent a metal sylphon bellows; and, when the catch holding R is released, the dome D descends and so the volume A is increased. C_1 and C_2 represent cameras. A picture of the completed apparatus is shown in Fig. 32.

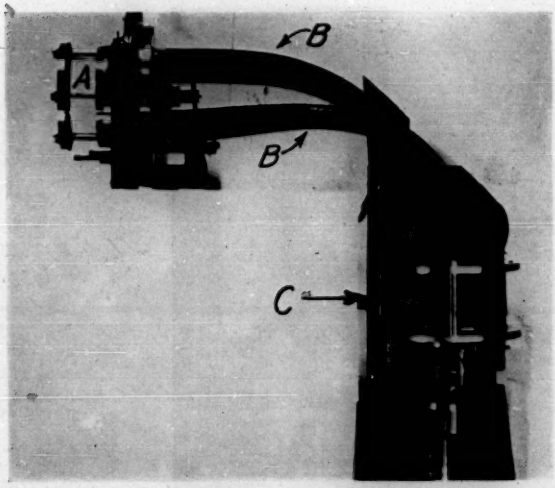
FIG. 32.



When the National Geographic Society-U. S. Army Air Corps stratosphere flight planned for last fall became imminent, Dr. Locher proceeded to devise another cloud expansion apparatus which conformed more particularly to the demands imposed upon it by the fact that it was to be used in the gondola attached to the balloon. It had to be light, and to require the minimum of manual operation.

Figure 33 is a picture of the apparatus, minus the cameras and subsidiary parts. *A* is the chamber in which the tracks are produced. It was provided with a rubber diaphragm as before; but the suction causing the motion of the diaphragm supporter was transmitted through the wide rubber tubes *B* from the expansion mechanism *C*. This was simply a cylindrical volume constructed from a large sylphon bellows. By means of a spring it was caused to elongate suddenly when a

FIG. 33.

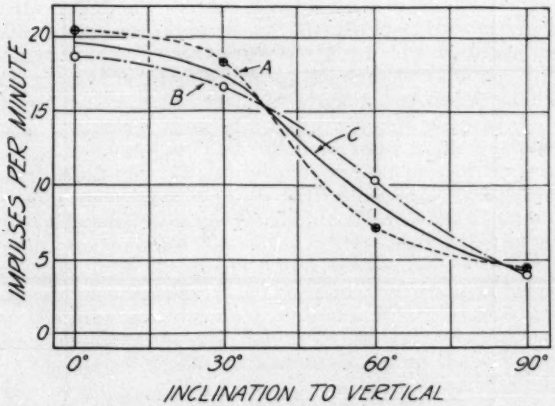


suitably placed catch was released. The motion of the rubber diaphragm was limited by two perforated metal plates. The apparatus comprised many details which cannot be enumerated here. It will suffice to say that it was automatically operated, through a relay, by three bundles of Geiger counters arranged out of line with one another, and provided with circuits so designed that the relay operated only when the counters discharged simultaneously. The mechanism which operated the expansion served also to take the photograph.

In this way photographs were taken only when a shower was known to have occurred; for only at the occurrence of a shower did the counters operate the relay.

Results from the Stratosphere Flights.—From the record salvaged from the National Geographic flight we were able to obtain the curves in Fig. 34, showing the relation between the number of cosmic-ray counts in our telescopes for different angles from the zenith at an altitude of 40,000 ft. The details of this figure are described in the legend, and it will be sufficient to discuss the full curve. At the same time, in Fig. 35, I give the result for the Piccard flight which was obtained at 53,000.

FIG. 34.

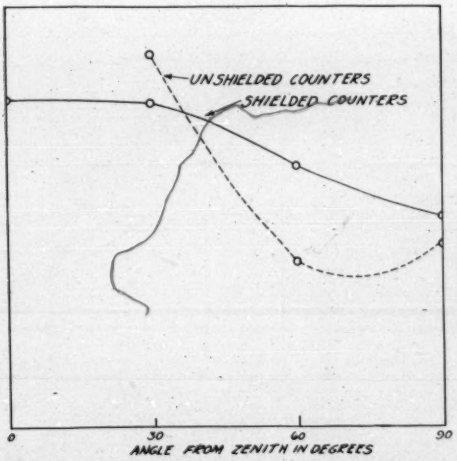


The curve A corresponds to data obtained from the sets without the shielding wall of counters. Curve B corresponds to the data for the other sets, and curve C is the mean.

The first matter of vital significance concerns a comparison of the intensities of the cosmic rays at different altitudes as measured by the counters and by ionization methods. By taking account of all directions, as is possible by utilizing such curves as those of Fig. 34 and Fig. 35, it is possible to calculate the relative values of ionization to be expected at different altitudes with that at sea level on the

assumption that the ionization is proportional to the number of rays [9] as measured by the counters. If we do this we find that the ionization should increase from sea level to 40,000 ft. by a factor of 60. Direct measurements by Professor Millikan's apparatus in the Settle flight gave 240 ions per cc. per second at this altitude. The increase of the ionization in a closed vessel from sea level to 40,000 ft. would consequently correspond to that given by the counters if the value at sea

FIG. 35.



level for ionization chambers were 4.0 ions per cc. per second. The sea level values given by Millikan, or corresponding to his observations range from 2.4 to 3.0. The value given by Compton is 1.9, and that by Hoffmann 1.0, but these are for shielded chambers. Even the value 3.0 is not sufficiently in agreement with 4.0 to warrant us in believing that the ionization and counter data correspond; and, a similar result was obtained from the Piccard data, although it is rather an

[9] I do not wish to imply belief in this assumption. In fact it is only made tentatively to show that the observations themselves possess the power to deny it.

interesting and significant fact that while the National Geographic-flight results and the Piccard-flight results agree in showing a much less rapid increase with altitude of the counting rate than corresponds to the increase with altitude of intensity as measured by ionization, the ratio of the counter-measured intensities and of the ionization-measured intensities for the National Geographic 40,000 ft. altitude and the Piccard 53,000 ft. altitude are practically the same.

Now the significant feature brought out by this comparison of intensity as measured by counters and by ionization is to the effect that the quality of the radiation alters with altitude. If the radiation consisted of rays of the same kind, or at any rate of the same properties, at all altitudes, then the number of events of any kind produced by the rays at different altitudes would be proportional to the number of rays. In particular the ionization would be proportional to the number of rays. However, these stratosphere flights suggest that the ionization increases with altitude more rapidly than the number of rays. In other words the potency of the rays to produce ionization increases with altitude. Closely related conclusions follow from the consideration of the Montgomery results at the top of Pike's Peak. Here the number of events took the form of atomic bursts, and these increased with altitude more rapidly than the cosmic radiation as measured by ionization and therefore, *a fortiori*, still more rapidly than the intensity of the radiation as measured by counters.

The second significant feature shown by the stratosphere data is the very large intensity in a horizontal direction. The intensity as given directly by the number of counts shows that at 40,000 ft. the horizontal intensity is 25 per cent. of the vertical. At 53,000 ft. it is more than 50 per cent. of the vertical. There is a certain complication inherent in the fact that a horizontal counter can receive rays entering through both ends and therefore at first sight should count double the number which it would count if it acted uni-directionally. Closer scrutiny of the matter, however, shows that the naïve view requires careful consideration, and that, on account of the finite angle of the counter, the latter would act as a uni-directional counter provided that no rays had an appreciable upward component. If the intensity is uniform

over a range of angle of projection falling above and below the horizontal to an extent greater than that determined by the angle of resolution of the telescope, then a horizontal telescope receiving rays from both ends does give a result double that representative of a proper interpretation of the data. However, it is true that the interpretation of the horizontal data has a certain range of ambiguity depending upon the nature of the paths of the rays themselves; but this ambiguity is not sufficient to disturb the qualitative and quasi-quantitative conclusion that the horizontal intensity is surprisingly large. At sea level, the horizontal intensity is negligible compared with the vertical, and this fact is attributable practically entirely to the fact that the horizontal rays have to travel through such a great thickness of the atmosphere. In the stratosphere this thickness is less, but the smaller thickness is by no means sufficient to account for the large horizontal intensity; for a simple calculation will show that a horizontal ray at 53,000 ft. will travel through a greater thickness of atmosphere than a vertical ray entering at sea level. Hence, if absorption were the only factor concerned, and if the rays entered the atmosphere equally in all directions, we should expect for the horizontal direction at 53,000 ft. a smaller ray intensity than for the vertical rays at sea level. As a matter of fact the apparent measured horizontal intensity at 53,000 ft. is about 29 times the sea level value for the vertical direction. I think we must attribute this large horizontal intensity to the effect of the earth's magnetic field in bending the paths of what would otherwise be more vertical rays into a horizontal direction. A few years ago I pointed out [10] that the entities which affect cosmic ray counters are probably for the most part secondary charged particles shot out from the atoms of the air by the more energetic primaries. These secondaries have energies which, while high, are so low compared with the primaries that they never could have reached the earth had they started from infinity, since they would have been turned back by the earth's magnetic field. Starting from some point in the higher regions of the atmosphere, however, they travel in a curved

[10] W. F. G. Swann, "On the Nature of the Primary Cosmic Radiation," *Phys. Rev.*, **43**, 945 (1933).

path. The radius of the path of electrons of 100-million volts energy would be about six kilometers. In the lower regions of the atmosphere such rays could not travel far enough to be bent through an appreciable angle. Coming from regions above 40,000 ft., however, a 1,000-million volt electron would not lose more than 50 per cent. of its energy in traveling a distance so large that in that distance its path would be bent through a right angle. We thus see how it is possible for rays incident more or less vertically, and even at other angles, upon our atmosphere to be bent around so as to enter in a horizontal direction at an altitude of 40,000 ft. We believe that the surprisingly high intensity at 40,000 ft. and 53,000 ft. for the horizontal direction shown in our experiments is representative of the action of the earth's magnetic field in bending the paths of these secondary rays.

There is a further interesting matter concerned with this curve showing the relation between intensity and zenith angle. Suppose the effect of the earth's magnetic field is to bend the paths of the secondary rays so that not only do some of them travel in a horizontal direction, but so that some travel actually in an upward direction, but not to an extent sufficient to cause the telescope at 60° zenith angle to count both ways. Then, the 60° readings will be consistent with the true shape of the intensity-zenith angle curve. However, the 90°, i.e. the horizontal, readings, will not preserve the true story of decrease of intensity with increase of zenith angle, but by virtue of the action of the telescope in counting both ways will deliver a bonus of counts which in the limit may result in doubling the number. Under these conditions, the observed intensity-zenith angle curve would show a minimum at some zenith angle—60° for example—followed by a rise to the 90° angle. The data recorded in Fig. 35 actually reveal such a dip in one of the curves. The magnitude of the dip may be below the limits of the experimental error, but the general flatness of the curve for large zenith angle is potentially evidence of the phenomenon in question.

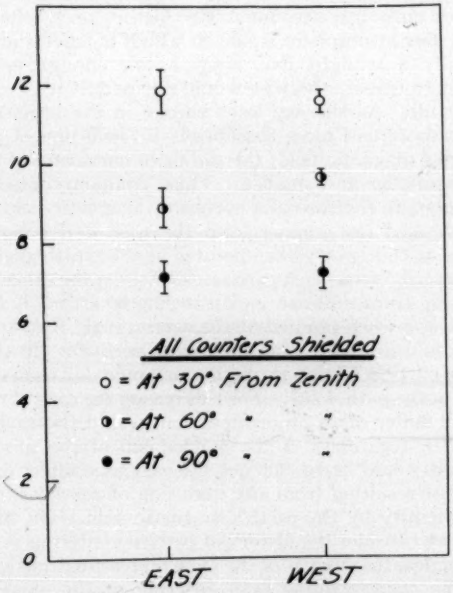
I now turn to the azimuthal asymmetry effects obtained in the stratosphere flights. The records necessary for this study were destroyed in the National Geographic flight, but were complete from the Piccard flight. The chief difficulty arises

of course from the limited number of observations which it was possible to obtain in the relatively short period of the flight. The rays come in at random, and to obtain a true average for any direction one must continue the experiments sufficiently long to secure a large number of counts. If in a steady rain one could count the number of drops falling upon a square foot in one minute, and should find it to be 100, and if he should take 100 drops per second as the average fall per square foot, he would make an error which might be in either direction, and which on the average would amount to about 10 drops per minute. If, on the other hand, his observations extended for ten minutes, and he counted a thousand drops he would make an average error of the square root of 1,000, that is about 30. Whereas the ten drops forms a 10 per cent. error on the hundred, however, the 30 drops forms only a 3 per cent. error on the thousand. To obtain an average accuracy of 1 per cent. for the intensity in any direction, one would have to continue the experiments long enough, to secure 10,000 counts. Luckily the counts come rapidly in the stratosphere; but the fact that one has to divide one's time between the various azimuthal directions makes this question of the number of observations obtainable in the time available the ultimate thing which limits the accuracy of the results. Every additional successful flight adds further information to the story, however.

In Fig. 36 I have averaged the intensities for a range of 40° on each side of the east, and for 40° on each side of the west, and have plotted on the east and on the west lines the two corresponding points. The short vertical line attached to each shows the average uncertainty caused by the limited number of observations. I have made such plots for 30°, 60° and 90° from the vertical. Those for 60° from the vertical show a 10 per cent. difference in favor of the west direction, and this, in its simplest interpretation at any rate, is an indication of an excess of positives in the primary radiation in harmony with the results found by Dr. Johnson at lower altitudes. However, I think that we must realize that the interpretation of these azimuthal directional effects at high altitudes is attended with complicating considerations which are not present in the observations at low altitudes. This

arises from the fact that the distance which a charged particle can travel in the rarified air of the stratosphere is so much greater than the corresponding distance at sea level, that while no electron, regardless of the energy, could have its path bent through an appreciable angle at atmospheric pressure, since it would complete its range before such bend

FIG. 36.



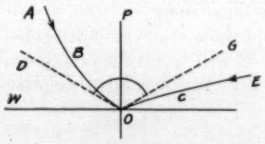
had become appreciable, at high altitudes the path bending in the atmosphere can play a part, for the low-energy electrons, secondaries, and possibly also primaries. The net result of this is to produce a situation which will be clear from the following.

A very direct story of the dependence of the azimuthal asymmetry upon the combined effect of the earth's magnetic

field and of atmospheric pressure, but one not very consistent with the facts available from the flight, may be told in terms of the view that the primary rays are the things which are measured in our telescopes. Although so many facts seem to demand that it is secondary electrons for the most part which are measured, and that the secondary rays exceed by many times in number the number of the primary rays, we shall first examine the question from the angle which takes the primaries only into account. The history of a primary ray entering our atmosphere is one in which it travels at first in practically a straight line, since a low enough energy to permit it to travel otherwise would not permit it to reach the earth at all. As the ray loses energy in the atmosphere it becomes more and more susceptible to deviation of path by the earth's magnetic field; the radius of curvature of its path becomes smaller and smaller. Thus, confining ourselves for the moment to the case of a horizontal magnetic field, a positively charged ray coming from the west and entering our telescope at *O*, Fig. 37, when pointed at the zenith angle *POD*, would describe some such path as *ABO*. On the other hand, a ray coming from the east, and traveling so as finally to enter the telescope when pointed at the zenith angle *POG* (equal to *POD*) would describe some such path as *ECO*. In the path *ECO* the particle travels through much more air than does the particle in the path *ABO*. For this reason the rays of the type *ECO* will suffer more absorption than would the rays of the type *ABO*, regardless of the mechanism of the absorption. The result would be to enhance the east-west effect over and above that resulting from any exclusion of particles from the earth's vicinity by the earth's magnetic field. On the other hand, if we consider the history of particles entering at smaller zenith angles, the story is of the type represented in Fig. 38, in which the corresponding rays entering at the same zenith angles east and west are again represented by *ECO* and *ABO* respectively. Here the air path difference is less than before, and the enhancement of the east-west effect would be less. For large zenith angles, however, the ray *ECO*, Fig. 37, would not exist at all, since to enter the telescope at nearly 90° to the vertical would necessitate the primary ray having come from below the horizon. These conclusions remain quali-

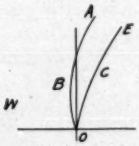
tatively the same when the arguments are applied for an inclined magnetic field. Presumably, therefore, the enhancement of the east-west effect would increase with zenith angle, and attain its greatest value at a zenith angle equal to 90°. However, the data given in Fig. 36 do not support, immediately, such a story as that deduced above, since they give very little east-west effect at 90° and a considerable one at 60°,

FIG. 37.



with a reversed effect of small size at 30°, which effect may be below the limit of accuracy of measurement, however. Of course, if the rays should be bent so as to have an upward path to an extent sufficient to make full use of the angle of resolution of the telescope, there would be no *measured* asymmetry for the horizontal direction, since, under these conditions the telescope operates from both ends.

FIG. 38.

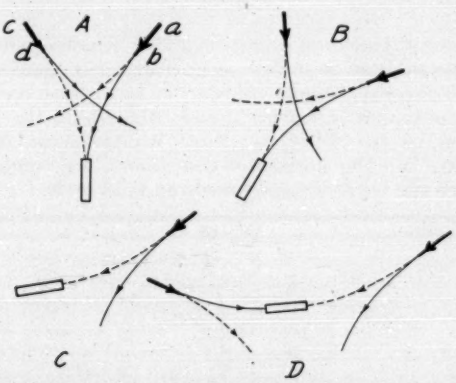


As already stated, the large horizontal intensity suggests that we invoke the effect of the earth's magnetic field on relatively low-energy electrons to bend their paths so as to feed the horizontal direction from those initial directions of the projected secondaries which are of smaller zenith angle. We shall then examine the consequences of assuming a picture in which the primaries eject secondaries from the atoms in pairs, positive and negative, which for simplicity we shall

assume of equal characteristics as regards energy and absorbability. We shall, moreover, suppose that by the time these secondaries enter our telescope they have experienced a considerable angular deviation in path—a deviation of perhaps 45° or more. Let us now examine the behavior of our telescope, first as regards the rays initiated by the symmetrical part of the primary radiation. Again we shall confine our description to the case of a horizontal field. The reader will readily verify that the conclusions reached will apply qualitatively for an inclined field.

If the telescope is vertical it will be fed with secondaries at the top only. It will receive a positive secondary from the primary ray *ab*, Fig. 39, *A*, and a negative secondary from

FIG. 39.



the ray *cd*. We represent the positive secondaries by full, thin lines, and the negative secondaries by dotted lines, the primaries being represented by full, thick lines. Fig. 39, *A*, then shows the history of all the rays concerned.

Now let us turn the telescope as shown in Fig. 39, *B*. It again receives rays through only the top end, and receives both positives and negatives.

Let us now turn the telescope as in Fig. 39, *C*. It now receives through the top end only negative electrons, because

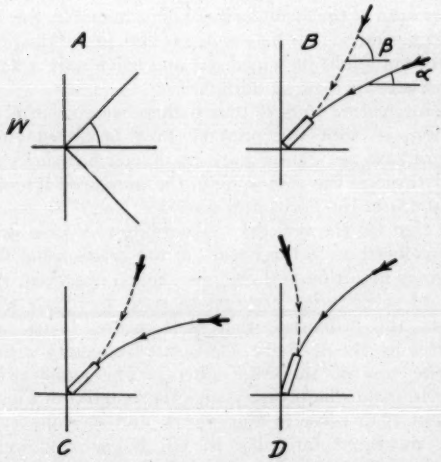
positives would have to have been initiated by primaries which came well below the horizon. Through the bottom end it receives, perhaps, as yet nothing; but on turning it a little further, the situation is that represented in Fig. 39, *D*. The telescope now receives rays from both ends, negatives from the top and positives from the bottom. It is natural to expect, therefore, a rapid fall in intensity with zenith angle at some angle qualitatively represented by Fig. 39, *C*, followed by a rise with further increase of zenith angle. The angle at which the minimum would take place might depend upon the characteristics of the secondaries as determined by the energies of the primaries, so that for a range of energies of the primaries the minimum might be wiped out and leave only a flattening as represented in Figs. 34 and 35.

It is interesting to note that if there were no atmospheric absorption, so that the primary rays produced the same number of rays per cm. of path no matter how far they had traveled through the atmosphere, the measured intensity for the telescope in the horizontal direction would be exactly the same as that for the vertical. According to a view presently to be developed as to the nature of the relationship between the primary radiation and the phenomena observed, the production of secondaries per cm. of path increases with the energy of the primaries, this phenomenon being, in fact, responsible for the decrease of measured intensity with depth below the top of the atmosphere. The same principles conspire to make the primary rays represented in Fig. 39, *D*, less potent than those in Fig. 39, *A*, and so cause the horizontally measured intensity to fall below that vertically measured.

Turning now again to the case of asymmetry, we may for purposes of discussion dissect out the asymmetrical primary positive rays, and concern ourselves only with the story of the positive and negative secondaries which they produce. For any given energy of ray, there is a cone to the east, Fig. 40, *A*, such that all primary rays of less than a certain energy are excluded from the cone. The smaller the cone, the greater the energy, and, therefore, the larger the contribution to the intensity by the totality of the rays which are excluded; and so the larger the contribution to the intensity

of the asymmetry. If we were not concerned with the exceptionally large effect of the magnetic field on the secondaries, the direction of our telescope at which exclusion below a certain energy occurred would be determined by the direction of the boundary of the cone for that energy. Let E_0 be the energy concerned. With the magnetic field present, however, the situation is as represented in Fig. 40, *B*. The primaries whose positive secondaries are excluded are now

FIG. 40.



those whose energy lies below that for the smaller cone of semi-angle α. The rays excluded are those corresponding to a primary energy below E_0 plus something. As far as this effect is concerned, the asymmetry would be increased. However, the exclusion angle for the primaries which send negative secondaries into the telescope is β, and the rays excluded are those corresponding to primaries below E_0 minus something. Thus the contribution of the negative secondaries to the asymmetry is diminished by the magnetic field. Hence, as a result of both actions there is a com-

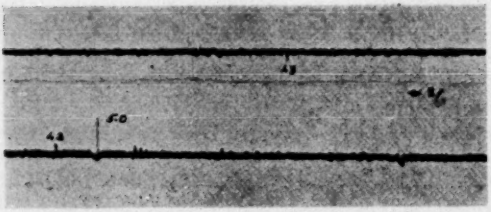
pensation, and it may well be that the asymmetry is not altered by the magnetic field. The story persists until the stage is reached which is represented in Fig. 40, *C*. At this stage the cone of exclusion for the primaries which send positive secondaries into the telescope is zero, and the range of energy exclusion is the greatest. All primary rays below a certain energy E_1 characteristic of the latitude and magnetic field are excluded. While E_1 is the largest energy figuring in the exclusion, it is not necessarily the largest energy possessed by the primary rays. Now, as we increase the zenith angle of our telescope further, and remembering that the path bending of the secondaries is not determined by anything but the properties of the secondaries and the magnitude of the magnetic field, we see that the primaries which would be necessary to produce positive secondaries which could enter the telescope would have to come from below the horizon. We do not have to go far beyond the condition represented in Fig. 40, *C*, therefore, before the primary rays concerned in sending positive secondaries into the telescope would be cut out by the earth or by the great thickness of the lower atmosphere. The result of this would consequently be to exclude suddenly, for a slight increase of zenith angle above the value for Fig. 40, *C*, in addition to the rays lying below E_1, all rays. At this zenith angle, the asymmetry should, as a consequence, show a large increase above the value determined by the normal principles which determine exclusion. On the other hand, when the telescope becomes horizontal, conditions of symmetry resulting from the power of the telescope to count in both directions will reduce the measured asymmetry to zero. The plots in Fig. 36, suggest a maximum asymmetry at zenith angle 60°, a practically zero asymmetry at 90°, and at zero degrees.

For small zenith angles, the conditions correspond to those in Fig. 40, *D*, and are in line with the general principles already developed. The asymmetry for zenith angle 30°, as shown by Fig. 36, is probably below the limits of uncertainty determined by the limited number of observations.

Before leaving the subject of stratosphere measurements, I may say that, in my judgment, one of the most important things to be done in cosmic-ray measurement is a measurement

of the vertical intensity with counters at different altitudes, not only at altitudes such as those aimed at in stratosphere flights, but also at altitudes such as can be reached by open basket balloons; and it is hoped that such an investigation may be carried out in connection with the forthcoming stratosphere flight. The reason for the importance of this investigation lies in the fact that practically all theories of the nature of cosmic-rays strike, in the first place, at the number of rays within fixed limits of angle measurable after passage through known thicknesses of the atmosphere. The measurements of ionization in a closed vessel contain a story which depends upon this more fundamental story but which is complicated in

FIG. 41.



The figure shows a reproduction of two actual records. The thin vertical lines, such as are shown at the places marked 1.3 and 5.0, represent atomic bursts. The heights of these lines is a measure of the sizes of the bursts.

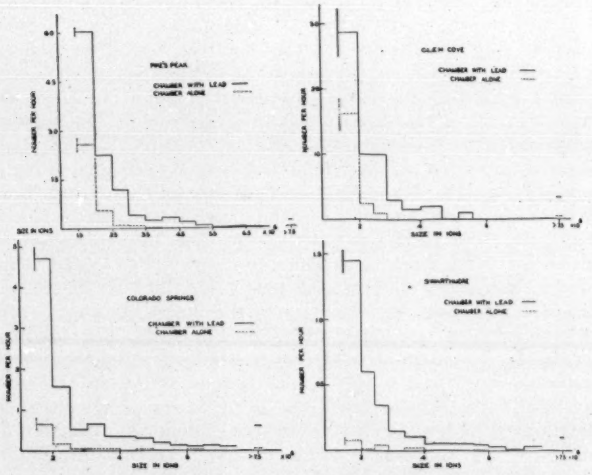
the first place by the inclusion of rays from all directions, and in the second place by the nature of the relation between the number of the rays and the ionization produced in a closed vessel, a relation which, as we have seen, is not a simple one.

Experiments Upon Atomic Bursts at Mountain Altitudes.—I have already referred in passing to the experiments on atomic bursts carried out by Dr. and Mrs. Montgomery at high mountain altitudes, and to the apparatus used, which I will not describe in detail since a description of it has already been published.[11] It is of interest to show Fig. 41, however, which shows an actual picture of the kind of records obtained, and

[11] C. G. and D. D. Montgomery, "Variation with Altitude of the Production of Bursts of Cosmic-Ray Ionization," *Phys. Rev.*, **47**, 429 (1935).

which will be understood from the legend attached. It is customary to plot curves showing by the ordinates the numbers of bursts lying between an assigned small limit of sizes at various average sizes as represented by the abscissæ. The graphs obtained in this way by the Montgomerys are shown in Fig. 42, in which the legend will explain the details.

FIG. 42.



Frequency distributions of bursts at the four elevations.

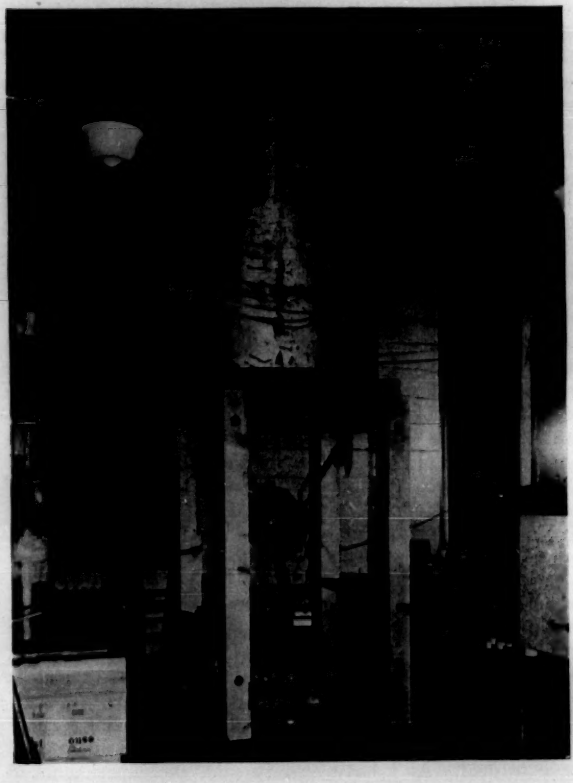
The observations were made at the summit of Pike's Peak (altitude 14,000 ft.), Glen Cove (11,400 ft.), Colorado Springs (6,000 ft.) and Swarthmore (sea level). The significant conclusions to be drawn from these observations are to the effect that (1) the number of bursts of all sizes increase with altitude at about the same rate, (2) the rate of production of bursts increases with altitude proportionally to the square of the cosmic-ray intensity so that while the cosmic-ray intensity increases by a factor of about 5 from sea level to

the summit of Pike's Peak, the frequency of bursts increases by a factor of 25.

The Mutual Induction of Atomic Bursts.—Some time ago, Dr. Locher, while examining the results of atomic bursts in the cloud expansion chamber, found that the showers of rays which form the bursts did not come all from one point. He was led to conclude that the whole shower was of a composite nature, and that probably a small shower initiated by the primary cosmic rays resulted in the emission of entities, believed by him to be neutrons, which stimulated secondary showers in other places with the result that these secondary showers carried on the process to the extent of producing a partial explosion extending through the whole of the substance in which the shower was produced. For this reason, it occurred to me that it should be possible to stimulate showers in a body, A, by the actual creation of showers in an entirely separate body, B. To test this fact, Dr. and Mrs. Montgomery and I carried out the experiment represented in Fig. 43.[12] The tank contained water, the amount of which could be varied, and the atomic bursts produced in the walls of the iron sphere suspended below it could be observed. It was found that the frequency of the bursts increased with the thickness of the water and then diminished with further increase. The increase of burst-production with increase of water is attributed to the stimulation of bursts in the iron sphere by the bursts produced in the water. The further diminution of bursts with increased thickness of water is attributed to a compensating action resulting from the absorption of the primary radiation by the water. The actual experiments showed an increase of 20 per cent. in the frequency of the bursts corresponding to 0.5×10^6 ions for a water thickness of 79 cms. To remove the possibility that the apparent increase of number of bursts in the sphere represented simply a measurement of spurts of ions produced in the sphere by rays which had come directly from the water, the iron sphere was replaced by a magnesium sphere, and the experiments were repeated. Any effect produced by the

[12] C. G. and D. D. Montgomery and W. F. G. Swann, "Enhancement of Cosmic-Ray Nuclear Bursts by the Presence of Subsidiary Material," *Phys. Rev.*, **47**, 512 (1935).

FIG. 43.



direct action of the rays from the water, without intermediary action in the walls of the sphere, should show itself just as well for the magnesium sphere as for the iron. However, no increase in burst frequency was found by increasing the thickness of the water when the magnesium sphere was used.

The fundamental significance of this experiment is that it substantiates the opinion expressed by Dr. Locher to the effect that a number of atoms participate in the production of the bursts. This gives us some relief from the difficulty inherent in the fact that the total energy required to produce some of these bursts is greater than the energy which could be reasonably expected to be liberated in one act in any atomic process which we know of, including the complete annihilation of heavy atoms. It also weakens considerably the claims of a rival theory which has been put forward to account for the origin of these bursts, and which, in view of its dramatic nature, I must not pass by without mentioning. Recent developments in atomic structure and the theories thereof have come to a realization of the possibility of the disappearance of matter and the accompanying appearance of radiant energy in proportional amount. They have also envisioned the reverse process in which radiant energy can be converted into material substance. The general idea of the production of these bursts, inherent in the theory to which I have referred, is to the effect that radiant energy in the form of a photon cosmic ray descends upon the substance under test. Occasionally such a ray comes into violent contact with the nucleus of an atom. Under these conditions it is supposed that nothing in particular happens to the atomic nucleus, but that the photon becomes mathematically irritated in such a manner as to cause it to decide to change its existence, commit suicide, and become resurrected as a group of particles. If you should ask for a crude analogy, I suggest that you think of a spiritualistic seance. The photon is the ghost, the shower of particles is the materialized ghost, and the atom is the medium.

I wish now to turn to the question of harmonizing some of these phenomena with which the experiments I have cited have to deal. As I have already said, the experiments of A. H. Compton and others require that at least 25 per cent. of the cosmic-ray intensity as measured at high latitudes must be initiated by primary charged particles, and the experiments of T. H. Johnson in equatorial regions add another 6 per cent. to this figure, making a total of 31 per cent. Moreover, this must still be regarded as a lower limit to the amount of the

measured radiation initiated by primary charged particles. Now this 31 per cent. is already enough to spoil the exponential law provided so conveniently by the photons, if, as a naïve view of the situation would suggest, the charged particle phenomena provide for a law of an entirely different kind. There being, therefore, no particular reason for clinging to photons as the saviours of the exponential law, and faced with the fact that at least 31 per cent. of the measured radiation is initiated by particles of the charged corpuscular nature, it is interesting to examine the possibilities inherent in the supposition that all of them are of that nature.

THE CORPUSCULAR THEORY OF THE COSMIC RADIATION.

According to the most naïve views, the exponential law would have to be provided for in the corpuscular theory by the existence of a wide range of incoming corpuscular energies which penetrated to different depths in the atmosphere depending upon the energies of the individual rays concerned. The amount of radiation to be found at any depth below the top of the atmosphere would depend upon the number of incoming electrons which happened to exist in the energy ranges necessary to reach the depth concerned; and the existence of an exponential law of absorption, or, if you prefer, of intensity with distance traversed, would necessitate the assumption of a special type of energy distribution in the incoming electrons necessary to secure that law. Even though we accept the necessary assumptions, however, a great difficulty remains. For under the simple conditions postulated it would turn out that the quality of the radiation would be the same at all altitudes. By this I mean that if at sea level, for example, we should find a certain distribution of energy among the rays, then at higher altitudes we should find the same relative distribution. The number of rays having any given energy would be greater at the higher altitude; but rays of all energies would be greater in the same proportion. At first sight this result is contrary to our intuitions and is contrary to what has presumably been generally believed; for it is natural to argue that the rays at high altitude would contain a preponderatingly larger proportion of low-energy rays than would those at low altitudes,

because the low-energy rays cannot penetrate to low altitudes. We must remember, however, that the rays which possessed high energy at high altitudes will by process of absorption become rays of low energy at low altitudes. They exist at low altitudes not because of the energy which they have there, but because of the energy which they had before they got there. If all of these matters are taken into account, then, as I have shown in a recent publication,[13] providing that one assumes the distribution of energies in outer space necessary to give the exponential law, it follows, as an inevitable consequence, that the quality must be the same at all altitudes.

Now the experimental data at our command resist, absolutely, harmonization with the view which concludes that the quality shall be independent of the altitude; for, upon such a view, the number of atomic bursts from lead, for example, would increase with altitude exactly in proportion to the measured number of cosmic rays themselves, whereas the experiments of the Montgomerys upon these bursts show that they increase much more rapidly than the cosmic-ray intensity, and similar results follow from the experiments of Johnson and of Rossi upon small showers of rays produced by the cosmic radiation. Again, I have shown how the stratosphere data have led us to the conclusion that the ionization produced by the rays in a closed vessel increases more rapidly with altitude than does the intensity of the rays itself, indicating once more a change of quality with altitude.

In order to overcome these difficulties, and at the same time secure the exponential law in what seems to be a more natural way, I have been led to formulate a view as to the mechanisms of the processes involved which, in its simplest aspect, and to a first approximation, takes the following form. Let us suppose that primary charged rays of a single energy enter the atmosphere uniformly in all directions and that as they travel through the atmosphere they produce along their paths secondary rays which, while possessed of energies such as those which figure in cosmic-ray phenomena, are nevertheless smaller than the energy of a primary ray. Let us suppose that these secondary rays are the chief entities which

[13] W. F. G. Swann, "The Nature of the Cosmic Radiation," *Phys. Rev.*, **47**, 575 (1935).

are observed in our cosmic-ray counters, and that they perpetuate the direction of the primaries which produce them. This last-named characteristic is hardly an assumption since it follows as a consequence of the laws of impact in which both the primary and secondary particles have very high energies.[14] In addition to this we shall assume, and this is the vital assumption, that the loss of energy per cm. of path is proportional to the energy of the primary ray. Or, in other words, we shall assume that the number of secondaries per cm. of path is proportional to the energy of the primary. It is then clear that, even though all the primaries come right through the atmosphere so that the number of them passing through a square foot is the same at all altitudes, the measured effect, depending as it does upon the number of secondaries, will increase with altitude because of the increase of primary energy with altitude. When we submit the matter to calculation we find that the intensity as measured by the number of rays follows exactly that law which we have called the exponential law. Moreover, it is possible without disturbing this result, to remove one of the postulates which it might seem that it was necessary for me to make. This postulate is to the effect that all incoming electrons have the same energy; for it can readily be seen that if we have a large number of groups of different energies, then each one will give rise to an exponential law of absorption, and, moreover, to the same exponential law of absorption. That is to say, rays of all energies will have the same absorption coefficient. It will thus be seen that the exponential law of absorption is secured as the result of the mechanisms of the processes taking place in the atoms, and does not rely upon some peculiar distributions of energies among the incoming rays. Again, having

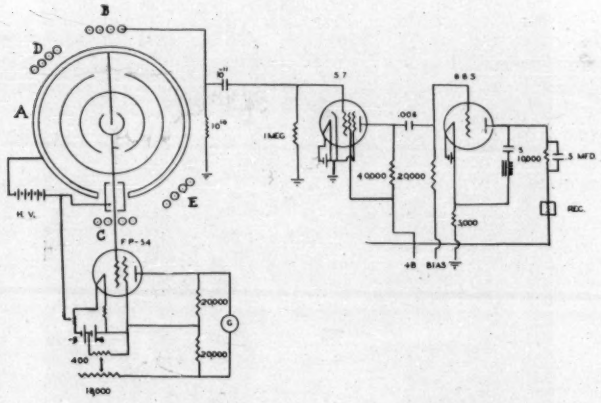
[14] Under the conditions in which the kinetic energy of the particles concerned is so high that the rest-mass is negligible, the relation between the momentum, M, of a particle and its energy, E, is $M = E/c$, and is the same as for the photon. Hence, whether photons or particles or both are involved, if undashed letters refer to the case of particles before impact, and if dashed letters refer to the case after impact, and if before impact only one of the particles possesses kinetic energy, the conservation of energy demands that $E = \Sigma E'$ and the conservation of momentum demands that $E/c = \Sigma(E' \cos \theta)/c$, where θ is the angle made by the direction of motion of the particle or photon after impact. It is impossible to satisfy both of these conditions unless $\theta = 0$ for all the entities concerned.

secured now a variation of quality with altitude, we are well prepared to see in a natural way how such experiments as those of the Montgomerys can be accounted for. Thus suppose that while the law of production of secondary rays from the air is one which makes the number produced under assigned conditions proportional to the energy of the primary rays, in the case of lead the rate of production of those secondaries which we call cosmic-ray bursts is proportional to a higher power of the energy than the first. Suppose, for example, that doubling the energy of the primary rays gives us four times the number of bursts. Then it is easy to see that, as in the case of the experiments of the Montgomerys, if the measured cosmic-ray intensity increases by a factor of five from sea level to the top of Pike's Peak, the number of bursts will increase by a factor of twenty-five. Moreover, we may well expect that the nature of the secondary rays produced will depend to some extent upon the energies of the primaries. In fact the secondaries themselves may in certain cases arise not directly from the primaries but through the intermediacy of photons produced by the primary, which photons in turn eject the electrons as secondaries from the atoms of air. There is thus ample provision for the situation found in which the ionization in a closed vessel varies with altitude in a manner different from that for the intensity of rays as measured by counters, since the ionization is produced by the secondaries and even by other entities, as neutrons, etc., which may be liberated by the primaries.

Further Experiment Showing that Efficiency of Cosmic Rays in Producing Atomic Bursts Depends upon the Primary Energy. —When it seemed that a natural explanation of the Montgomerys' results was to be found in the change of the energy of the primary ray with altitude, I decided to try an experiment to verify this conclusion in another way, for if we should select the rays which come in in the vertical direction, and those which come at an angle of 45° to the vertical, we should expect the latter group to have less energy than the former, on account of their greater journey through the atmosphere. We should therefore expect them to be less efficient than the former in producing these atomic bursts. To test this matter, Mr. Dean Cowie and I used an apparatus illustrated in Fig. 44,

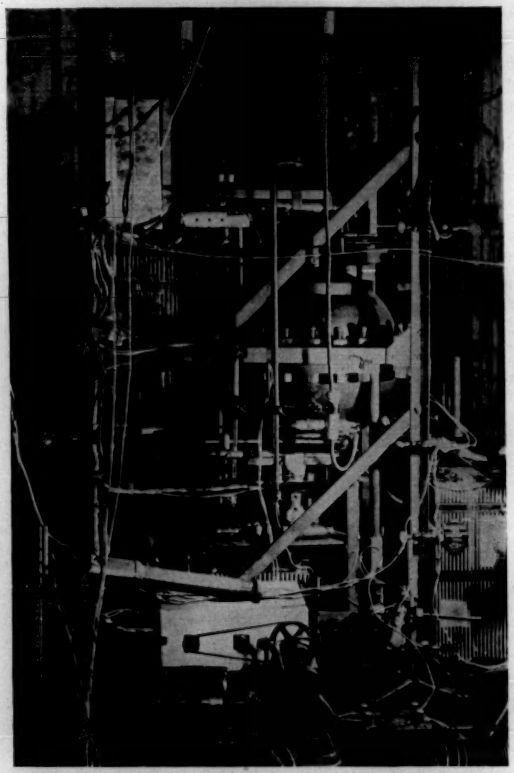
and shown pictorially in Fig. 45. Referring to Fig. 44, *A* is an iron sphere, *B* and *C* are two sets of counters arranged so that they will only produce a record if they discharge simultaneously. *DE* is another pair of counters arranged so as to record rays at 45° to the vertical. The central insulating system of the sphere was connected to a suitable recording system whose main feature was a P-54 pliotron feeding into an amplifying system which ultimately produced, upon a ballistic galvanometer, records of the atomic bursts produced

FIG. 44.



in the sphere. We thus recorded on one moving photographic record, (1) the galvanometer trace showing the atomic bursts, (2) the records of the counter discharges of the vertical counters, and (3) the records of the counter discharges of the 45° counters. It was then possible to pick out and count those atomic bursts which were associated with vertical rays and also those bursts which were associated with the 45° rays. The experiment showed that while over a period involving some thousands of counts, the number of counts obtained by the vertical and 45° counters were in the ratio 1.6 to 1, the corresponding numbers of atomic bursts (in-

FIG. 45.



volving more than 1.5×10^6 ions) were in the ratio of 10 to 1. Thus the vertical rays of high energy are shown to be much more efficient in the production of these bursts than are the 45° rays of lower energy.

Incidentally, the foregoing experiment gives an explanation of what has formerly seemed a peculiar fact, viz. that the

particles in atomic bursts seemed to travel almost exclusively downwards. If rays coming in at finite zenith angles co-operated to produce bursts, there seemed no obvious reason why the bursts produced by such rays should not show a symmetry with regard to the direction of the rays which produced them; and if this were the case, we should expect that many of the bursts would show symmetry for directions other than the vertical. An explanation of this phenomenon is now afforded by the very small number of bursts produced by rays coming in directions appreciably different from the vertical.

The elementary idea which I have formulated above to embody what may be the main principle in the story of corpuscular cosmic-ray phenomena, is naturally to be considered as only a first approximation. Before considering the extensions which should be made in it, it will be well to make a list of the outstanding facts which it must be the purpose of a theory to correlate. This list will embody many facts to which I have not yet referred, and some to which I have. The facts are as follows:

(*a*) The intensity for any angle θ obeys approximately an exponential law.—According to the analysis of Millikan, 90 per cent. of the radiation is to be accounted for by a component with coefficient of absorption μ equal to 0.5 per meter of water.[15]

(*b*) In so far as there is departure from the exponential law, it is in the direction of increased hardening (diminution of average coefficient of absorption) with distance traveled by the primary rays.

(*c*) The latitude diminution of cosmic-ray intensity in equatorial regions increases with altitude as shown by the experiments of A. H. Compton and his associates.

[15] The coefficient of absorption μ is the fraction by which the intensity changes per meter of air traversed, when the air is compressed to the density of water. It must be remarked that some caution must be observed in associating counter intensity measurements with ionization measured intensities, since the two are not proportional. For such deviation there is ample theoretical basis; but, pending more experimental facts upon this point, we must go on the basis that the characteristic features of the absorption curve as obtained by ionization methods are qualitatively the same as those obtained from counter data.

(*d*) The east-west effect defined as the ratio of the intensity, $I_{a\theta}$, of the asymmetrical part of the radiation to the sum, $I_{o\theta}$, of the intensities from east and west increases with altitude for a constant latitude, as shown by T. H. Johnson. It is of course understood that $I_{a\theta}$ and $I_{o\theta}$ refer to a definite zenith angle θ.

(*e*) While the east-west asymmetry increases with zenith angle for small zenith angles, it finally attains a maximum and then diminishes with further increase of zenith angle as shown by the experiments of T. H. Johnson, Alverez and Compton, and others.

(*f*) The east-west effect *increases* with decrease of latitude at a given altitude, as shown by T. H. Johnson.

Then we have a number of phenomena concerned with shower production or atomic bursts. They are:

(*g*) Calling $S(L)$ the number of showers or bursts of any character produced per unit volume in lead or other element of high atomic weight, and I the average intensity of the cosmic radiation, the experiments of the Montgomerys, and of Johnson and of Rossi, show that $S(L)/I$ increases with altitude.

(*h*) Calling $S(L)_\theta$ the number of showers produced per unit volume of lead by the cosmic rays received at the zenith angle θ, and I_θ the measured intensity of the rays at this angle, $S(L)_\theta/I_\theta$ diminishes with increase of θ. This results from the experiment performed by Mr. Cowie and myself, cited earlier.

(*i*) Writing R for the ratio of $S(L)/I$ at latitude $\varphi = \varphi_1$, to the corresponding value at $\varphi = 0$ it appears that R is less than unity for all values of φ_1 at which observations have been made.

(*j*) If R_h is the value of R at altitude h, and R_0 is the value at sea level, R_h/R_0 is greater than unity.

(*k*) The showers produced by rays from east and west show less asymmetry than do the east and west intensities themselves.

The phenomena under *i*, *j*, *k* result from measurements made by T. H. Johnson.

Formulation of a More Complete Theory.—The existence of a law approximately exponential as required by (*a*) has been provided for by the elementary theory already cited. In fact,

the theory provides for this law as an exact consequence. The fact (*b*) is not provided for in the elementary theory.

The elementary theory while accounting for an alteration of quality with altitude, provides for a coefficient of absorption which is the same for all energies and altitudes. Now it is fundamental to the theory of the action of the earth's magnetic field upon charged corpuscles that the effect of the field shall be greater the smaller the energy. Hence, phenomenon (*c*) tells us that the apparent coefficient of absorption for the more deviable, soft, low-energy rays must be greater than for the less deviable, high-energy, hard rays.[16] Hence, our theory must provide for an increase of coefficient of absorption with decrease of energy. If such is provided for, an explanation is provided immediately for (*d*), since the asymmetrical rays have, by the fundamentals of the theory of asymmetry, less energy than the others. By the same provision, (*e*) is also explained, since increase of zenith angle is equivalent to increase of primary path. The phenomenon (*f*) is an immediate consequence of the known theoretical conclusion that the range of energies involved in the asymmetrical rays increases with decrease of latitude. While therefore it is in harmony with the theory proposed, it does not invoke any assistance from that theory, but stands on its own merits.

Thus, with a reservation as regards (*b*), which reservation will presently be removed, all of the phenomena (*a*) to (*f*) inclusive are consistent with an extension of the elementary theory in the direction of providing for an apparent coefficient of absorption which increases with decrease of energy of the primary rays.

Turning, moreover, to the phenomena of shower production and the like, phenomena (*g*) and (*h*) receive a natural explanation on the lines already formulated, to the effect that shower production in lead depends upon a power of the primary energy higher than the first, or at any rate higher than that which determines the shower production in air, which in turn determines the apparent intensity as measured.

[16] In the case of rays which do not obey a true exponential law, it is convenient to introduce the concept of an apparent coefficient of absorption applicable to any point, and defined, for that point, by $-u_a = (1/A)dA/dx = d/dx(\log A)$, where A is the quantity measured and dx is an element of path.

If, for purposes of mathematical illustration, we suppose that I is proportional to E^n, where E is the primary energy, and n is positive; and if, following the ideas already formulated with regard to shower or burst production in lead, we assume $S(L)$ proportional to E^{n+k}, we have that $S(L)/I$ is proportional to E^{n+k}/E^n, i.e. to E^k; and the quantity defined as R, under (i) is proportional to $(E_1/E_0)^k$, where, as under (i) subscript zero refers to the equator and subscript unity, to the latitude $\varphi = \varphi_1$. Thus, since on the average E_1/E_0 is less than unity, R is less than unity, which is in harmony with the fact (i).

Again, if subscripts s and h refer, respectively, to sea level and to the altitude h, we have

$$R_h/R_s = [(E_1/E_0)_h/(E_1/E_0)_s]^k = [\{(E_1)_h/(E_1)_s\}\{(E_0)_s/(E_0)_h\}]^k.$$

Now if we introduce for the E's coefficients of absorption μ_1 and μ_0 we have

$$R_h/R_s = e^{kh(\mu_1-\mu_0)}.$$

If further, as already necessitated by the facts (c), (d) and (e) we permit an extension of the elementary theory in the direction of making the coefficient of absorption of primary energy increase with decreasing energy, then μ_1 is greater than μ_2 and R_h/R_s is greater than unity, which is in harmony with (j). In all of the foregoing, it should be recognized that the magnitude of k depends, in all probability, upon the size of the shower or burst.

Turning now to fact (k), if E_a refers to the average energy of the rays which determine asymmetry and if E refers to the average energy of all the rays coming in the directions concerned, the normal asymmetry is determined by, say, $(E_a/E)^n$ where, as before, n is a positive number which, as a matter of fact is nearly equal to unity. In line with our fundamental hypothesis as to the dependence of burst or shower production upon primary energy, we conclude that the asymmetry in the shower production in lead is determined by $(E_a/E)^{n+k}$. Hence, regardless of the value of n since E_a is less than E we have, for the showers or bursts, an asymmetry which is *less than the normal asymmetry for the intensity*, the

ratio of the two being in fact $(E_u/E)^k$. This is in harmony with fact (*k*).

Summarizing what has been written above, it is clear that, with the reservation already referred to in respect of (*b*), all of the phenomena from (*a*) to (*f*) inclusive may be correlated on the basis of an extension of the elementary theory in such a direction as to make the coefficient of absorption of the primary energy and the closely related apparent coefficient of absorption of the measured radiation increase with decrease of energy of the primaries. Moreover, all of the phenomena from (*g*) to (*k*) inclusive may be correlated on the basis of the said extension combined with the fundamental hypothesis already formulated as to the relation between primary energy and shower or burst production. It now remains to be shown how the coefficient of absorption concerned may be made to depend on the primary energy.

As already implied, a necessary extension of the principles of the elementary theory is one to provide for a coefficient of absorption which increases with decrease of primary energy. The details of this matter will not be given here since they are published completely elsewhere.[17] It will suffice to say that provision of the end desired may be made in more ways than one, the most natural being one in which to the rate of loss of energy in air usually from shower production and proportional to the primary energy, we add a part which is independent of the energy. Such an assumption leads to an expression for the coefficient of absorption μ of the form

$$\mu = \mu_0 + \gamma/E,$$

where μ_0 and γ are constants. The expression thus provides for increase of μ with decrease of E.

Finally, it becomes necessary to turn to the elements involved in realizing the requirement (*b*). At first sight, the requirement of decrease of average coefficient of absorption with distance traveled seems contrary to the principle that the effective coefficient of absorption of the individual rays increased as the rays lose energy—a principle demanded by the asymmetry effect. The difficulty is only transitory,

[17] Since this report was presented the complete theory has been published in the *Phys. Rev.*, **48**, 641 (1935).

however, for now we introduce once more the idea of a wide range of primary energies entering the atmosphere, a hypothesis which is indeed required by the latitude and directional effects. Then, although each of these rays may *soften* as a result of its passage through the atmosphere, a suitably chosen energy distribution among the entering rays will insure that the measured radiation as a whole will harden with approach to sea level.

In the foregoing sketch of a theory we have implied the existence of a charged corpuscular entity which flies through the atmosphere, and by loss of energy in its path, by means of the mechanisms we have described, produces the phenomena observed. It is possible, however, to make a concession to the photon hypothesis to the extent of supposing that the entity actually traveling through the atmosphere and functioning as a primary is in reality a photon. In this case, it is necessary to endow the photon with the characteristics we have imparted to the corpuscle in the foregoing theory. The continual loss of energy must be visioned as accompanied by a continual change of wave-length of the photon; and, indeed the entity which we have envisioned as the primary in its journey through the atmosphere may be a photon for one part of its path and a corpuscle for another. It may even exist in the form of a composite entity, part in the form of a photon and part in the form of a corpuscle. However, even should we make such concession to the photon idea, it is nevertheless necessary to assume that the entity which functions as the primary entity in its approach to the earth is a charged particle, or at any rate that a large proportion of such entities are of the charged particle nature; for, only by such assumption may the latitude and directional effects be accounted for. If photons function as the apparent primaries in passage through the atmosphere, these photons must have been formed, in part at any rate, from the true primary charged particles on entry into the atmosphere and have received from them their directional characteristics through the principle of perpetration of velocity at impact already cited.

MISCELLANEOUS INVESTIGATIONS ON NUCLEAR PHYSICS.

The Energy Spectrum of Positrons Generated in Lead by Thorium C″ Gamma Rays.—Occasionally when a gamma ray strikes an atomic nucleus it experiences a transformation into a positively and a negatively charged particle. The Einstein relationship between mass and energy would describe the process in terms of the following relation:

$$h\nu = m_+c^2 + m_-c^2 + k_+ + k_-,$$

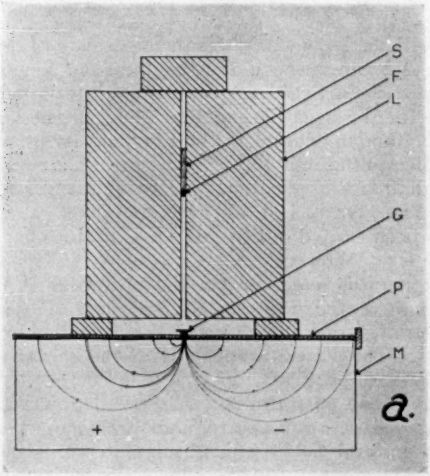
where h is Planck's constant, ν is the frequency of the gamma ray, m_+ and k_+ are respectively the mass and kinetic energy of the positive particle, m_- and k_- are the corresponding quantities for the negative particle, and c is the velocity of light. The fundamentality of the Einstein law in its bearing upon problems of atomic physics is so great that verifications of it in all of its applications are of primary importance. For this reason, Dr. G. L. Locher has conceived an experiment which has been carried out by Mr. C. L. Haines and himself, and which is as follows:

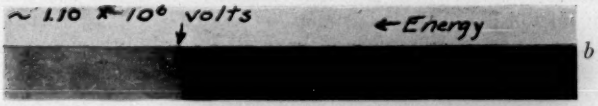
The apparatus used in the investigation is diagrammatically represented in Fig. 46. S is a source of Thorium C″, and is the emitter of gamma rays; it is surrounded by a heavy lead shield. The softer components of the gamma rays are reduced by a filter F of lead, one centimeter thick. The gamma rays that pass through F proceed downwards to a de Broglie-type beta-ray spectograph, whose magnetic poles M give a uniform field perpendicular to the plane of the diagram. The gamma rays enter the space between the poles (which space is kept at high vacuum) through a sheet of metal foil G. This foil is the "generator" of the positron-electron pairs. The paths of the positrons and of the electrons are bent in opposite directions, in semi-circles, and impinge on a photographic film P, inside the spectrograph, thereby registering themselves by blackening the film. The film was 50 cm. long.

The energy of the Thorium C″ gamma rays corresponds to 2.62×10^6 electron volts. The energy equivalents of the rest masses of the positron and electron are each 5.07×10^5 volts, so that the kinetic energy available for the positron and electron is $(26.2 - 10.14) \times 10^5 = 1.6 \times 10^6$ volts. We may

expect to find positron-electron pairs in which the kinetic energy ranges all the way between zero for the electron and 1.6×10^6 volts for the positron to 1.6×10^6 volts for this electron and zero for the positron. We might therefore expect to find the blackening on the photographic film to

FIG. 46.





extend from the center in Fig. 46 to the left and to the right up to the points corresponding in each case to 1.6×10^6 volts. However, the blackening on the negative side is complicated by the fact that a large portion of the negative electrons arriving at the film are not created from gamma rays but are ejected from G as recoil electrons and photo-

electrons. Nevertheless, all of the positrons owe their origins, presumably, to the annihilation of gamma rays. For this reason only the limit of the blackening to the left in Fig. 16 has significance. It was found to occur at an energy 1.10×10^6 volts as shown by the actual reproduction of the film in *b*, Fig. 46 which was made with an exposure lasting seven weeks.[18]

INDUCED RADIOACTIVITY AND NUCLEAR TRANSFORMATION BY GAMMA RADIATION.

The discovery during the last few years that radioactivity may be induced in substances by bombardment with alpha rays, neutrons and high energy deutons has raised the question of whether gamma rays may be capable of producing such effects. With the exception of a few elements, the binding energies of atomic nuclei are too high to justify expectation that the actual emission of particles might follow irradiation by gamma rays; but, it may not be unreasonable to expect something which we may call "nuclear fluorescence," with subsequent emission of gamma rays.

To test some of the above matters, Dr. G. L. Locher, and Dr. L. H. Rumbaugh proceeded, through the courtesy of Drs. G. M. Dorrance and B. A. Hughes, of the Oncologic Hospital of Philadelphia, to use the four grams of radium in equilibrium with its products possessed by the hospital.

Fourteen elements were irradiated for periods of 20 to 24 hours, each at a mean distance of approximately 3 cm. from the gamma ray source. The radiation passed through about 2 grams/cm.^{2} of material (platinum and aluminum in which the radium was mounted, and copper of the container of the elements). The irradiated elements were transferred separately, in from 40 to 120 seconds, to a distant Geiger-Müller counter equipped with a thin window equivalent to 2.5 cm. of air. The counter was sensitive to the gamma radiations from 1.5×10^{-11} grams of radium in the position occupied by the tested elements. The recording system contained a

[18] Since this report was presented, the discrepancy between the values 1.10×10^6 and 1.6×10^6 has been largely removed by realization that the thorium C'' used contained radium as an impurity. The value 1.10×10^6 is in close harmony with the value to be expected from some of the radium photons.

mechanical counter and a chronometer which could be photographed automatically at set intervals.

The irradiated elements were Li, Be, B, C, N, O, Mg, Al, P, Cl, K, Cu, Bi, U. No certain induced radioactivity of half value period greater than one minute involving either the emission of gamma radiation or of particles of sufficient energy to penetrate the counter window was detected in any of the elements irradiated. These experiments are being continued with an apparatus more suited to observing short-lived processes.

In connection with the foregoing experiments, Drs. Locher and Rumbaugh observed the ejection of neutrons from beryllium by gamma radiation, reported by Szilard and Chalmers,[19] by inducing the radioactivities characteristic of bromine and of silver when exposed to neutrons. Both bromine and silver when placed in the center of a mixture of 100 grams of BeO and 200 grams of paraffin gave initial counting rates several times the normal background.

A possible nuclear process associated with the above phenomenon may be written symbolically.[20]

$$ {}_4\mathrm{Be}^9 + h\nu = {}_2\mathrm{He}^4 + {}_2\mathrm{He}^4 + {}_0n^1. $$

Drs. Locher and Rumbaugh attempted to induce the 3 minute positron activity of aluminum with alpha particles from the above reaction. A surface of 1,000 cm.^{2} of aluminum in the form of a stack of thin sheets separated by powdered beryllium was exposed to this gamma radiation. No positron annihilation radiation from the stack of sheets could be observed. Drs. Locher and Rumbaugh conclude that the negative result may be explained if the photo cross-section of the beryllium nucleus is less than 10^{-29} cm.^{2}, or, alternately, if the energy balance is less than that given by mass spectroscopy for the reacting nuclei, so that the alternate reaction,

$$ \mathrm{Be}^9 + h\nu = {}_4\mathrm{Be}^8 + {}_0n^1, $$

may predominate. The latter explanation is in agreement with Aston's recent suggestion that the accepted mass of helium should be increased by 0.002 mass unit.

[19] L. Szilard and T. A. Chalmers, *Nature*, 134, 494 (1934).

[20] In conformity with the customary notation, subscripts refer to atomic number and superscripts to atomic mass. ${}_0n^1$ refers to a neutron.

Conclusion.—In addition to the foregoing investigation, others are in progress and will be reported upon in due course. I refer to the experiments of Dr. L. H. Rumbaugh on the collection of Isotopes in large amounts, and to the further experiments of Mr. W. E. Ramsey and myself upon the efficiency of ionization by cosmic rays. I may refer also to an investigation by Dr. W. E. Danforth and myself, which is nearing the completion of its first stages, and which concerns those mysterious phenomena having to do with the passage of cosmic rays through magnetized iron.

In concluding this, I fear, lengthy address, I should like to take the opportunity of expressing our appreciation to the American Philosophical Society for a grant which has enabled us to carry out some of the investigations which I have referred to. It is also a pleasure to acknowledge the assistance of the Carnegie Institution of Washington which has been very generous in supporting the field work of Dr. Johnson's investigations. Assistance such as we have received from these two groups is of the greatest value at times such as the present when the conditions of financial stress have treated our income none too kindly. Finally I cannot conclude without expressing my personal pleasure at the presence with us this evening of Mrs. F. Bartol Dalley and Miss E. Josephine Brazier, members of the Bartol family which has been responsible for our being able to amuse ourselves in this way, and to make at the same time, I hope, some contributions to the progress of that science with which the name of Philadelphia is so intimately associated.

APPENDIX.

Publications of the Bartol Research Foundation from April 18, 1934 to April 17, 1935.

Coincidence Counter Studies of the Corpuscular Component, *T. H. Johnson. Phys. Rev.*, **45**, No. 9, 569–585, May 1, 1934.

Studies of the Corpuscular Component of the Cosmic Radiation, *T. H. Johnson. Transactions of the Amer. Geophysical Union*, Fifteenth Annual Meeting, 1934.

Radioactivity Induced by Neutron Bombardment, *A. Bramley. Phys. Rev.*, **45**, No. 12, 901–902, June 15, 1934.

Report on the Work of the Bartol Research Foundation, 1933–1934, *W. F. G. Swann.* JOUR. FRANK. INST., **218**, No. 2, 173–241, August, 1934.

The Significance of J. Clay's Ionization Depth Data in Relation to the Nature of the Primary Cosmic Radiation, *W. F. G. Swann. Phys. Rev.*, **46**, No. 5, 432–434, September 1, 1934.

The Annihilation of the Proton, *A. Bramley. Phys. Rev.*, **46**, No. 5, 438–439, September 1, 1934.

Emission of Electrons from Cold Metal Surfaces, *C. C. Chambers.* JOUR. FRANK. INST., **218**, No. 4, 463–484, October, 1934.

The Relation of the Primary Cosmic Radiation to the Phenomena Observed, *W. F. G. Swann. Phys. Rev.*, **46**, No. 9, 828–829, November 1, 1934.

Concerning the Recovery Time of Geiger-Müller Counters, *W. E. Danforth. Phys. Rev.*, **46**, No. 11, 1026–1027, December 1, 1934.

Measurement of Absolute X-Ray Intensities and Absolute Sensitivity of X-Ray Film with a Geiger-Müller Counter, *G. L. Locher and D. P. LeGalley. Phys. Rev.*, **46**, No. 12, 1047–1051, December 15, 1934.

North-South Asymmetry of the Cosmic Radiation in Mexico, *T. H. Johnson. Phys. Rev.*, **47**, No. 1, 91–92, January 1, 1935.

Concerning the Fluctuations of Current in a High Resistance, *G. W. Barnes.* JOUR. FRANK. INST., **219**, No. 1, 100–107, January, 1935.

Chemical Engineering in the Stratosphere, *Jean and Jeannette Piccard. Industrial and Engineering Chemistry*, **27**, pp. 121–127, February, 1935.

The Origin of the Hardening of Cosmic Rays in Passing Through Matter, *W. F. G. Swann. Phys. Rev.*, **47**, No. 3, 250, February 1, 1935.

Evidence for a Positron-Negatron Component of the Primary Cosmic Radiation, *T. H. Johnson. Phys. Rev.*, **47**, No. 4, 318–319, February 15, 1935.

On the Electrostatic Deflection of Cosmic Radiation, *W. E. Danforth and W. F. G. Swann. Phys. Rev.*, **47**, No. 5, 421, March 1, 1935.

The Enhancement of Cosmic-Ray Nuclear Bursts by the Presence of Subsidiary Material, *C. G. and D. D. Montgomery and W. F. G. Swann. Phys. Rev.*, **47**, No. 6, 512–513, March 15, 1935.

The Variation with Altitude of the Production of Bursts of Cosmic-Ray Ionization, *C. G. and D. D. Montgomery. Phys. Rev.*, **47**, No. 6, 429–434, March 15, 1935.

A Circuit for the Analysis of Geiger-Counter Pulses, *W. E. Ramsey and M. R. Lipman. Rev. Scientific Instruments*, **6**, 121–125, April, 1935.

The Nature of the Cosmic Radiation, *W. F. G. Swann. Phys. Rev.*, **47**, No. 8, 575–577, April 15, 1935.

Coincidence Counter Studies of the Variation of Intensities of Cosmic-Ray Showers and Vertical Rays with Barometric Pressure, *E. C. Stevenson and T. H. Johnson. Phys. Rev.*, **47**, No. 8, 578–580, April 15, 1935.

The Variation of Cosmic-Ray Intensity with Direction in the Stratosphere, *W. F. G. Swann and G. L. Locher.* National Geographic Society Contributed Technical Papers, Stratosphere Series, No. 1, pages 7–14.

Papers Presented at Various Meetings But Not Published.

Presented before the American Physical Society.
Washington Meeting, April 26–28, 1934.

What Fraction of the Primary Cosmic Radiation is Positive? T. H. Johnson.

Ionization Spurts Resulting from Cosmic Ray Entities, W. F. G. Swann and W. E. Ramsey.

Pittsburgh Meeting, December 27–29, 1934.

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Measurements of the Angular Distribution of Cosmic-Ray Intensities in the Stratosphere with Geiger-Müller Counters, W. F. G. Swann and G. L. Locher.

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Further Analysis of Cosmic-Ray Results of the Piccard Stratosphere Flight, W. F. G. Swann and G. L. Locher.

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Characteristics of Geiger-Müller Counters Filled with Different Gases, C. L. Haines.

Effect of Cosmic-Ray Energy upon Burst Production, W. F. G. Swann and D. B. Cowie.

Corpuscular Theory of the Cosmic Radiation, W. F. G. Swann.

Presented at the Washington Meeting of the American Geophysical Union, April 26–27, 1935.

Contribution of the Cosmic Radiation to the Ionization of the Upper Atmosphere, T. H. Johnson.

Earth-Magnetic Analysis of the Cosmic Radiation, T. H. Johnson.

Polarized Light.—Physicists know that polarized light waves vibrate in only one direction or plane. By devising means of controlling polarized light in a convenient form, its utilization can be widespread.

In the February number of *Safety Engineering* there is note made of an announcement and demonstration by the inventor, EDWIN H. LAND, a Boston scientist, of a substance known as Polaroid. It appears to be a clear, colorless glass and light that has passed through it appears as ordinary light. The rays, however, are polarized and can be controlled. For instance, when the lenses of blinding headlights of a motor car are equipped with Polaroid, their extreme brilliance appears dimmed when viewed through the windshield of another motor car which is also equipped with Polaroid. Simultaneously other objects appear brilliantly illuminated. The reason for this is that due to the Polaroid used in the lenses and windshield, all the rays are vibrated in a controlled plane. Road tests demonstrated that the whole of the approaching car could be seen, even to the exhaust fumes from the rear; pedestrians are clearly seen as if no car were approaching. It is stated that the glaring headlight hazzard can be eliminated at last.

Another use of polarized light is recorded in the February number of *Studio Light*, a publication by the Eastman Kodak Company. The Eastman Pola-screen, a new invention, enables the photographer for the first time to polarize light. The invention which makes Pola-screen possible is a polarizing substance in sheet form containing countless minute rod-like crystals which are all parallel to each other. The Eastman Pola-screen incorporates this sheet material cemented to, or between glass plates. When two such screens having parallel planes are placed together the second screen will pass the light polarized by the first, but if one screen is rotated the light diminishes until, with vibration planes at right angles, practically no light is allowed through. This is very useful in photography because of the way in which surfaces reflect light. Reflected light is composed of two parts known as the specular and diffuse components. A large proportion of the light reflected from a polished surface is specular, and practically all light reflected from a dull surface, such as chalk, is diffuse. The specular reflection at about 30 deg. from a flat surface is polarized by the act of reflection and hence may be removed by means of the Pola-screen. Placed over a lens, one screen can be rotated to a point where part or all of the objectionable specular reflection is cut out and the object can be photographed by the remaining diffuse light. Pola-screen placed over studio lights makes possible reflection control to a high degree and has special application in copying difficult subjects.

R. H. O.

A STUDY OF THE QUALITY, THE DESIGN AND THE ECONOMY OF CONCRETE.

BY

INGE LYSE,

Research Associate Professor of Engineering Materials, Lehigh University, Bethlehem, Pennsylvania.

(Concluded from June issue.)

b. Reinforced Concrete Members.

The effect of the strength of the concrete is also important in the design of reinforced concrete members. The total cost of such a member is made up of the cost of the concrete in place and the cost of the reinforcement in place, plus whatever additional cost which may be due to curing, finish, etc. For the sake of comparison this additional cost item may well be neglected, and the economy of the member studied on basis of cost of materials in place. Reinforced concrete members subjected to compressive stresses will utilize both the concrete area and the steel area to the full extent, while members subjected to flexural stresses will utilize only that portion of the concrete area which is in compression. Consequently these two types of reinforced concrete members must be considered independently of each other. The increase in compressive strength may well be of advantage for column sections, while the most economical slab or beam may result from a lower strength of the concrete.

In the following study only the fundamental principles are considered. When the solution of the problem on basis of these principles can be established, it is a simple matter of routine computation to apply the same method to any particular condition. Since the ultimate strength of a reinforced concrete member is the criterion for its usefulness, this strength will be used in studying the different sections. Building codes and regulations may impose various factors of safety for different members and also various factors for the two materials, concrete and steel, in the reinforced concrete

member, but when the fundamental principles of the economical relationship are known, it is relatively simple to apply them to the conditions laid down by the regulating bodies.

1. *Compression Members.*

The extensive investigation carried out at the University of Illinois and Lehigh University under the sponsorship of the American Concrete Institute (33, 34) and the supplementary investigation carried out at Lehigh University (35), have established the following law for the ultimate load carrying capacity of reinforced concrete columns. The strength of a reinforced concrete column is made up of 85 per cent. of the cylinder strength of the concrete times the total area of concrete plus the yield-point stress of the longitudinal reinforcement times its area plus an additional load carried by the spiral reinforcement if such is used in sufficient amount, or:

$$S = 0.85 f_c' A_c + f_s A_s + k' f_s' A_s', \tag{26}$$

where S represents the strength of the column, f_s and f_s' the yield-point stress of longitudinal and spiral steel respectively, and A_s and A_s' the area and equivalent area of longitudinal and spiral steel, and k' is the effectiveness ratio of the spiral reinforcement in terms of the strength added beyond the strength of the protective concrete shell. The spiral reinforcement will not contribute materially to the strength of the concrete until the protective shell has spalled off. For tied columns and columns having a small amount of spiral reinforcement the last term in the strength equation will disappear and we have:

$$S = 0.85 f_c' A_c + f_s \cdot A_s. \tag{27}$$

Assuming that the working stress is a certain percentage of the strength of the column such as in the German regulations, the economic study becomes that of finding when the concrete or the steel will contribute most to the strength per unit of cost. The cost of tied reinforced concrete columns is:

$$P = p_c' A_c + p_s A_s + \text{Finish, etc.}, \tag{28}$$

where p_c' and p_s are unit prices of concrete and steel in place. Since the cost of finish, etc. does not vary appreciably with

the size of the columns used, and is smaller for a strong concrete due to smaller cross-sectional areas than for a weak concrete, this has been neglected in the following study.

The unit price of concrete in place varies much in accordance with the variation in the cost of materials which have been studied under plain concrete. As far as the concrete itself is concerned, it is therefore of great advantage to use a mix which produces a reasonably high strength.

The most economical reinforced concrete column is the one having the lowest cost per unit of strength. The unit cost of the concrete in the column is:

$$\frac{p_c' A_c}{0.85 f_c' A_c} = \frac{p_c'}{0.85 f_c'} \tag{29}$$

and the unit cost of the longitudinal steel is:

$$\frac{p_s A_s}{f_s A_s} = \frac{p_s}{f_s} \tag{30}$$

if welded reinforcement is used, but where about 20 per cent. excess steel has to be used for spliced reinforcement. Thus we have for columns having welded reinforcement: p_s/f_s must be equal to or less than $p_c'/0.85 f_c'$ if the steel shall be equal to or more economical than concrete. Since the price of steel is usually given in terms of tons and that of concrete in terms of cubic yards, it is necessary to relate these terms:

1 cu. yd. steel = 490 lb. × 27 = 13,200 lb. = 6.6 tons

Thus $6.6(p_s/f_s)$ must be equal to or less than $p_c'/0.85 f_c'$ which gives:

$$p_s = \frac{p_c'}{6.6 \times 0.85} \times \frac{f_s}{f_c'} = 0.18 p_c' \frac{f_s}{f_c'} \tag{31}$$

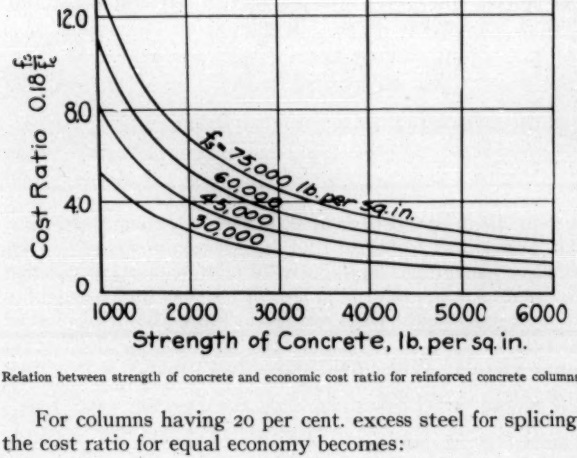
for f_s = 45,000 lb. per sq. in. and f_c' = 3000 lb. per sq. in. we have:

$$p_s = 0.18 \frac{45{,}000}{3000} \cdot p_c' = 2.7 p_c'. \tag{32}$$

The cost of steel in place (per ton) must thus be less than 2.7 times the cost of concrete in place (per cubic yard) if the steel shall become the more economical material. In Fig. 34

the ratios between cost of steel in place and cost of concrete in place for which the steel is as economical as the concrete, are given for several yield-point stresses of steel and strengths of concrete. Except for very weak concrete and very high strength steel, the concrete will by far be the most economical material under the present-day price ranges.

FIG. 34.



Relation between strength of concrete and economic cost ratio for reinforced concrete columns.

For columns having 20 per cent. excess steel for splicing, the cost ratio for equal economy becomes:

$$p_s = \frac{1}{1.20} \cdot 0.18 \frac{f_s}{f_c'} \cdot p_c' = 0.15 \frac{f_s}{f_c'} \cdot p_c'. \qquad (33)$$

Since the longitudinal reinforcement contributes its full yield-point strength to the strength of the column, regardless of amount and grade of steel, the economy of the steel is directly proportional to the ratio between its cost and yield-point stress. That is, p_s/f_s is the economy measure of the steel so that in general high strength steel is more economical than ordinary grade because the cost does not increase in direct proportion to the yield-point stress.

If the building regulations contain different factors of safety for concrete and steel as is often the case, the same principles as those given above can be used by simply using working stresses (that is, strength divided by factor of safety) instead of the full strength values f_c' and f_s. Often the required factor of safety for concrete is considerably greater than that for steel, so that the cost ratios given in Fig. 34 will be raised. However, even with these different factors of safety, the concrete of ordinary and high strength will be more economical than the reinforcement where the requirement for minimum cross-sectional area of the columns is not the determining item.

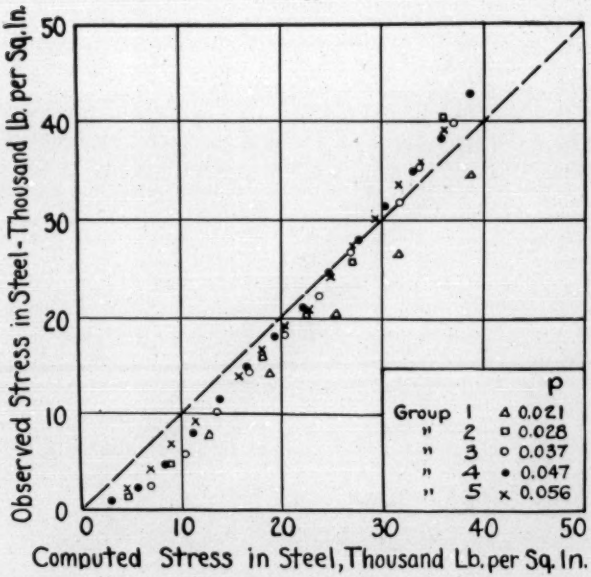
When spiral reinforcement is used in reinforced concrete columns, it must add more strength than the strength of the protective shell outside the spiral if it shall be of any value. For this spiral reinforcement to be more economical than longitudinal steel, it must have a lower cost in place per unit of strength added to the column. Consequently the effectiveness ratio in terms of strength beyond strength of protective shell must more than offset the extra cost of spiral steel. Under ordinary conditions this would seldom occur except for a very large amount of spiral of high grade steel. However, many building regulations permit lower factor of safety for spiral columns than for tied columns, which to a certain extent, increases the economical possibility of the spiral. The problem of producing the most economical reinforced concrete column is therefore solved by simply analyzing the cost per unit of permitted working stress for the different materials which contribute to the strength.

2. *Flexural Members.*

In reinforced concrete slabs and beams, the concrete is supposed to take the compressive forces and the longitudinal reinforcement the tensile forces. In order to study to what extent the concrete could be utilized provided sufficient reinforcement was available, an extensive investigation was carried out at Lehigh University (23). All beams were designed to fail in the compressive area of the concrete and therefore had an excess of reinforcement. The percentage of

reinforcement ranged from 2.1 to 5.6 with steel of an average yield-point stress of 64,800 lb. per sq. in. The strength of the concrete as determined on standard control cylinders, ranged from 1390 to 5740 lb. per sq. in. Deformation measurements were made on top of beam and at location of reinforcement, and in some cases near the computed neutral axis of the beam.

FIG. 35.

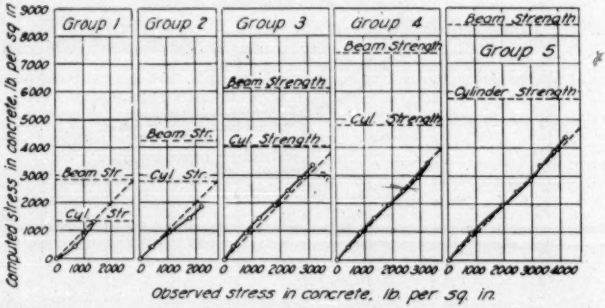


Relation between observed stresses in reinforcement and stresses computed according to American Concrete Institute specifications.

In Fig. 35 the relation between the observed stresses in the steel determined by multiplying the strains at the reinforcement by its modulus of elasticity, and the stresses computed by the ordinary straight line formula specified in the 1928 Code of the American Concrete Institute, is shown for the five different strengths of the concrete. The broken line indicates

equal observed and computed stresses. On the whole, the observed stresses group themselves so well along the computed stresses, that the straight line stress distribution may be considered well suited for the design of stresses in the steel. The relation between the observed and computed maximum stresses in the concrete is shown in Fig. 36. The so-called observed stresses were secured by taking that stress on the stress-strain diagram for the control cylinder of the beam at which the strain corresponded to the strain measured on the top of the beam. The broken line gives the condition for equal computed and observed stresses. Although the stress-

FIG. 36.



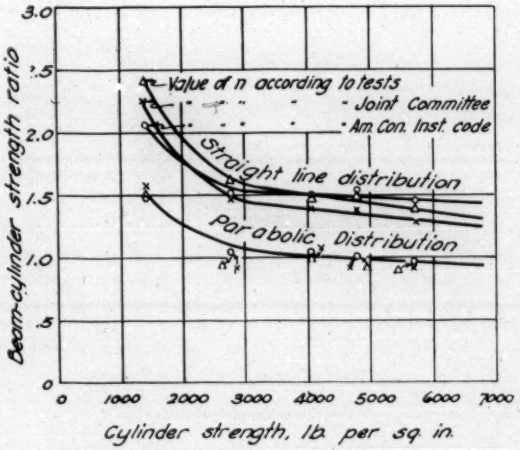
Relation between observed stresses in concrete and stresses computed according to American Concrete Institute specifications.

strain diagram for the control cylinders could not be carried up to the ultimate strength of the cylinders, the data indicate that for stresses at least up to the strength of the control specimens, the stresses in the concrete computed by means of the straight line formula agreed very well with the observed stresses. Thus it may be concluded that for stresses far beyond the permitted working stresses, the straight line formula gives a dependable method of designing concrete members subjected to flexural forces.

The ratio between computed maximum stresses in the concrete at time of failure of the beam and the strengths of the

control cylinders is shown in Fig. 37, both for straight line and parabolic stress distribution. The computed maximum stresses in the beam are considerably higher than the cylinder strength for straight line distribution, particularly for low strength concrete. Using n according to tests, this ratio varies from 2.41 for low strength to 1.39 for high strength concrete. For concrete of strength of 3000 lb. per sq. in. and more, the ratio is not far from 1.50. For parabolic

FIG. 37.



Effect of strength of concrete on beam-cylinder strength ratio.

stress distribution the beam-cylinder ratio was about 1.00 for strength of concrete of 3000 lb. per sq. in. and more.

The above study leads to the conclusion that the straight line stress distribution is satisfactory for design of reinforced concrete beams and slabs provided a maximum strength of concrete in flexure of approximately 1.50 times the strength of the control cylinder is used. The tests also showed that the location of the neutral axis of the beams of different strengths of concrete did not vary very much. Actually the

ratio (ratio of distance between the compressive and tensile forces to depth of beam) varied from a high value of 0.837 for the 1390 lb. per sq. in. concrete, to as low as 0.814 for the 5740 lb. per sq. in. concrete. For beams having sufficient reinforcement for the development of the full compressive value of the concrete, the j value may therefore be considered constant at about 0.82. This is due to the fact that the location of the neutral axis is not only depending upon the ratio of the moduli of elasticity of steel and of concrete, but also upon the percentage of reinforcement. The position of the neutral axis for straight line distribution is given by:

$$k = \sqrt{2pn + (pn)^2} - pn. \tag{34}$$

Since an increase in strength of the concrete will decrease the ratio n and require an increase in the percentage p, the location of the neutral axis is only slightly affected by the variation in the strength of the concrete and will for simplicity be taken as constant in the following study. Per unit width of slab or beam the ordinary straight line stress distribution gives:

$$1.5f_c' = \frac{2M}{k \cdot j \cdot d^2} \tag{35}$$

or

$$d = 2\sqrt{\frac{M}{3 \cdot k \cdot j \cdot f_c'}}. \tag{36}$$

The effective depth of the beam thus decreases inversely with the square root of the increase in cylinder strength. The cost per unit length of a reinforced concrete slab or beam of unit width is:

$$P = d \cdot p_c' + A_s \cdot p_s + z \cdot p_c' + \text{Finish, etc.,} \tag{37}$$

where p_c' and p_s represent unit cost of concrete and steel in place, and z is thickness of protective cover (distance from center of longitudinal reinforcement to surface of concrete). Neglecting the cost of the protective cover, $z \cdot p_c'$, the cost of the concrete is:

$$d \cdot p_c' = p_c' \cdot 2\sqrt{\frac{M}{3 \cdot k \cdot j \cdot f_c'}} = \frac{2p_c'\sqrt{\frac{M}{3k \cdot j \cdot}}}{\sqrt{f_c'}}. \tag{38}$$

For a given moment, M, the cost of the concrete in the effective depth of the section varies inversely with the square root of the strength of the concrete. Since the permitted minimum depth of the protective cover is the same regardless of strength of concrete, its cost will increase with the strength of the concrete. The amount of steel required to prevent failure of the reinforcement will increase with the increase in strength of the concrete. The area of reinforcing steel is given by:

$$A_s = \frac{M}{j \cdot d \cdot f_s} = \frac{M}{j \cdot f_s \cdot 2\sqrt{\frac{M}{3 \cdot k \cdot j \cdot f_c'}}} = \frac{\sqrt{3 \cdot M \cdot k \cdot j \cdot f_c'}}{2j \cdot f_s} \quad (39)$$

or the amount of reinforcement varies directly with the square root of the strength of the concrete. Since the amount of steel increases with the increase in strength of the concrete and the volume of concrete decreases, the total cost of the section may either increase or decrease with the increase in strength of the concrete, depending upon the relative cost ratio for steel and concrete. In order to study the relation between economy of section and strength of the concrete Fig. 38 has been prepared. This figure has been prepared on the following basis:

$M_{ult.}$ = 100,000 lb.-in. per inch of width,
f_s = 40,000 lb. per sq. in.,
j = 0.82 and $k \cdot j$ = 0.44,
D = 0.82.

The cost of the materials in the concrete is:

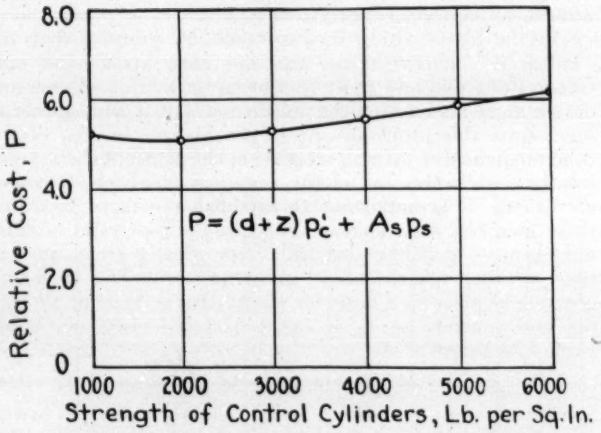
$$p = 4460 \cdot D \cdot p_a + (p_c - 0.85p_a)\frac{f_c' - A}{K}$$

$$= 3660p_a + (p_c - 0.85p_a)\frac{f_c' + 2570}{12} \quad (40)$$

when $f_c' = -2570 + 12c$. For $p_a = 0.10$ cents per pound and $p_c = 0.50$ cents per pound we have:

$$p = 366 + 0.415\frac{f_c' + 2570}{12} = 445 + 0.0346f_c' \quad (41)$$

FIG. 38.



Effect of strength of concrete on economy of reinforced concrete flexural member.

cents per cubic yard. If the cost of manufacture and placing be taken as \$4 per cubic yard of concrete or

$$p_c' = p + 400 = 845 + 0.0346 f_c' \qquad (42)$$

cents per cubic yard of concrete in place. Taking p_s = \$70 per ton or \$0.035 per pound in place and z = 1.0 in., the curve in Fig. 38 represents the relationship between cost of section and strength of concrete used. The relative cost of the flexural member is seen to decrease when the strength of the concrete increases from 1000 to 2000 lb. per sq. in., but to increase when the strength of the concrete increases beyond 2000 lb. per sq. in. The most economical concrete mix to use for flexural members is thus one having a strength of about 2000 lb. per sq. in. However, the reduction in dead weight of the member and the consequent reduction in all structural members from the use of high strength material will raise the strength for the most economical concrete mix. The important item brought out in Fig. 38 is the fact that the strength

of the concrete has a relatively slight effect upon the economy of flexural reinforced concrete members.

In the above study it was taken for granted that the "balanced" reinforcement was the most economical one. General practice and most textbooks on reinforced concrete design make this a foregone conclusion, but it is desirable to investigate this problem. As shown above, the cost of the concrete increases with an increase in the depth of the flexural member, while the cost of the necessary steel reinforcement decreases. It is important to establish the facts regarding these increases and decreases. Since the cost ratio of reinforcement to concrete does not vary greatly from time to time, we may use the above given unit prices for steel and concrete in place as a basis for study, that is, steel at $70 per ton and concrete at $p_c' = 845 + 0.0346 f_c'$ cents per cubic yard. As before:

$$P = d \cdot p_c' + A_s \cdot p_s + z \cdot p_c' = (d + z) p_c' + A_s p_s. \quad (43)$$

Solving this equation for different maximum stresses in the concrete of a given strength and for steel of a given yield-point stress, we obtain the results given in Fig. 39. The moment used was 100,000 lb.-in. per inch of width and $f_s = 40{,}000$ lb. per sq. in. The n ratio was taken in accordance with the 1928 recommendations of the American Concrete Institute, that is, $n = (30{,}000/f_c')$. The strengths of concrete used for this figure were 2000 and 4000 lb. per sq. in. with stresses in flexure of as much as 1.50 times the compressive strength of the control cylinders. The percentage of steel required for various concrete stresses is given by the usual formula for straight line distribution:

$$p = \frac{0.5}{\frac{f_s}{f_c}\left(\frac{f_s}{n \cdot f_c} + 1\right)} \quad (44)$$

and the effective depth of the concrete is

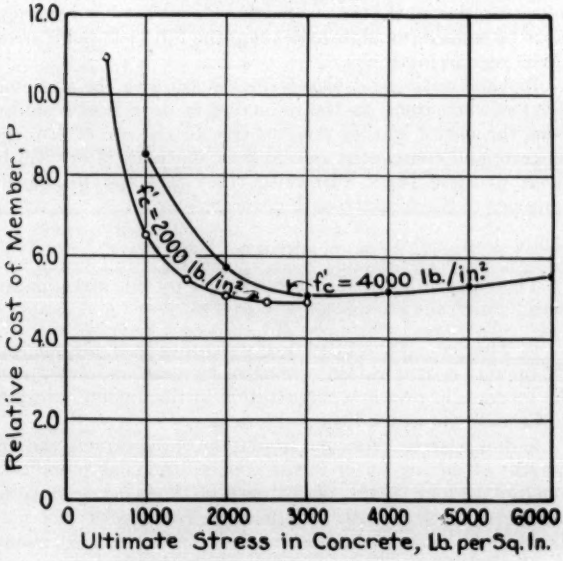
$$d = \sqrt{\frac{6M\left(\frac{f_s}{f_c} + n\right)^2}{nf_c\left(\frac{3f_s}{f_c} + 2n\right)}}. \quad (45)$$

The thickness of the protective cover was taken as 1.0 in.

V. 19

Figure 39 shows that the cost ratio decreases very fast when the stress of the concrete is increased from 500 to 1000 lb. per sq. in. At higher stresses the cost ratio approaches a constant value for the concrete having a strength of 2000 lb. per sq. in., while for the concrete having a strength of 4000 lb. per sq. in. the ratio actually increases slightly when the

FIG. 39.



Effect of stress in concrete on economy of flexural member.

stress in the concrete increases beyond 3000 lb. per sq. in. However, this increase in the cost ratio is very small and probably would be nearly eliminated when the decrease in dead weight of the section was considered. Consequently the balanced type of reinforcement is probably very nearly the most economical one for our present-day price ratios.

If other factors than the flexural stresses govern the size of the section, the above study does not solve the problem of most economical design. The factors which govern the design must be the basis for the economic study.

Since the yield-point strength of the steel is fully utilized in the reinforced concrete beams as well as in the columns, it becomes the criterion for the economy of both compression and tension reinforcement. It is important to note that for full utilization of the tension reinforcement the bond strength must be sufficiently high to develop the full yield-point stress of the reinforcing bars.

Because ordinary design formulas will give the economic effect of such items as the reduction in dead load resulting from the use of smaller sections due to the use of stronger concrete and consequent gain in floor space, no study will be given to these items. However, they will add to the advantages of the high-strength concrete.

SUMMARY.

The outstanding results brought out by this investigation were:

1. The Strength and practically all other desirable qualities of concrete except volume changes, increase uniformly with the increase in cement concentration in the amount of water in the concrete at the time of hardening.

2. For a given type and gradation of aggregates the net amount of mixing water in the concrete remains practically constant as long as the placeability of the concrete remains approximately constant. Changes in richness of mix may therefore be accomplished by simply substituting g_a/g_c pound of aggregate for each one pound change in the cement content.

3. The economy of plain concrete increases very markedly with the increase in strength, with variables such as gradation of aggregates and strength-quality of cement less important.

4. The cost ratio between steel and concrete for equal economy in reinforced concrete columns is: $p_s/p_c' = 0.18(f_s/f_c')$ for welded reinforcement and $p_s/p_c' = 0.15(f_s/f_c')$ for spliced reinforcement.

5. The strength of the concrete has relatively small effect

upon the economy of reinforced concrete members subjected to flexure.

6. The balanced reinforcement approaches the most economical design for present-day cost ratios and ordinary strength of the concrete.

7. The economy of the reinforcing steel is directly proportional to the ratio between its unit price and yield-point stress.

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NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

THERMAL EXPANSION OF COPPER-BERYLLIUM ALLOYS.

An investigation of copper-beryllium alloys, which have come into industrial use during the past few years, was undertaken to determine the effects of chemical composition and treatments on expansion. The beryllium contents ranged from 1.3 to 3.0 per cent., results previously obtained on other properties having indicated that this range included the useful alloys. The results, which are set forth in detail in RP890 in the June number of the *Journal of Research*, will be valuable to the electrical and aviation industries.

1. The expansion curves of quenched copper-beryllium alloys, containing 1.33 and 2.14 per cent. beryllium, showed critical regions which may be associated with structural changes accompanying aging.

2. Stabilization of copper-beryllium alloys may be accomplished either by tempering or by cold working.

3. There is no simple relation between the coefficients of expansion, chemical composition, and heat treatment of the copper-beryllium alloys investigated. Figure 14 of the publication indicates the effects of beryllium content, cold work, and heat treatment on the coefficients of expansion of these alloys.

4. The following table gives the ranges of the coefficients of expansion:

Beryllium Content	Average Coefficients of Expansion [1] per Degree C.		
	20 to 100° C.	20 to 200° C.	20 to 300° C.
Per cent.	$\times 10^{-6}$	$\times 10^{-6}$	$\times 10^{-6}$
0.00	16.8(2)	17.2 to 17.3(2)	17.6 to 17.8(2)
1.33	16.4 to 17.0(14)	15.9 to 17.3(11)	17.3 to 18.1(8)
2.14	16.5 to 16.7(9)	16.6 to 17.1(8)	17.5 to 18.0(7)
3.03	15.9 to 17.3(6)	16.0 to 16.9(4)	16.4 to 17.4(4)

[1] This table does not include coefficients of expansion for temperature ranges in which critical regions were observed. Each number in parentheses represents the number of expansion determinations.

* Communicated by the Director.

The coefficients of expansion of the copper-beryllium alloys do not differ from the corresponding value for copper by more than 8 per cent. of the latter value, whereas differences for the hardness, tensile strength, elongation and reduction of area shown in Fig. 8 of the publication, are considerably greater. For example, the tensile strength of copper-beryllium alloys may be more than 4 times as great as the tensile strength of copper.

5. The changes in length, density, and volume noted for both the quenched and the hard drawn alloys are somewhat larger than the small changes noted for the aged alloys. The changes in length, volume, and density of quenched copper-beryllium alloys depend upon the temperature and time of aging. The density of copper-beryllium alloys decreases with increase of beryllium.

ALTERNATING-CURRENT MAGNETIC COMPARATOR FOR TESTING TOOL-RESISTING PRISON BARS.

Prison bars are required to be tool resisting. In the interest of security, it is essential to be able to test them by some non-destructive method. The usual mechanical tests are not applicable on account of the peculiar construction of the bars, in which the tool-resisting quality is provided by hardened steel inserts. These are entirely surrounded by soft steel, which imparts the necessary degree of toughness and prevents easy access to the interior.

The Bureau has cooperated with the Federal Bureau of Prisons in the investigation of magnetic methods for testing tool-resisting prison bars. In the course of this investigation an alternating-current magnetic comparator has been developed which is suitable for testing not only prison bars, but also other types of steel and steel products.

The apparatus is simple to operate, portable, and fairly rugged. It takes current from the ordinary alternating-current lighting circuit. It is fully described in the June number of the *Journal of Research* (RP894).

TESTS OF EIGHT LARGE H-SHAPED COLUMNS FABRICATED FROM CARBON-MANGANESE STEEL.

High strength steel is being used more and more as a substitute for low carbon steel in structures such as bridges

and buildings, because of the substantial saving in material thus brought about. However, experience with this relatively new material is needed to develop the most satisfactory designs for the different structural members.

Columns are an important part of any structure, but comparatively few tests have been made on large columns fabricated from high-strength steel. It was because of this lack of information that the Port of New York Authority requested the cooperation of the Bureau in determining the strength and behavior under load of large H-shaped columns fabricated from carbon-manganese steel plates and angles. As a result, eight columns were tested and the properties of the material determined by tensile tests of coupons.

The strength of seven of these columns exceeded the capacity of the testing machine which was 10,000,000 pounds.

All the columns deflected in a direction perpendicular to the web.

The results of these tests which will be published in detail in the June number of the *Journal of Research* (RP896), indicate that large riveted columns of carbon-manganese steel, similar to these test columns, have satisfactory strength and behavior under load.

TESTS OF STEEL CHORD COLUMNS FOR THE KILL VAN KULL BRIDGE.

Compression members of steel structures, such as columns, may fail by buckling of outstanding legs of angles or of wide thin cover plates.

The Bridge Department of the Port of New York Authority when designing the lower chord members of the Kill van Kull Bridge between Port Richmond, Staten Island, and Bayonne, New Jersey, used large double-box type compression members made of carbon-manganese steel. Because the width of these cover plates was large compared with their thickness, the Port Authority requested the coöperation of the Bureau in an investigation of the behavior of these lower chords under load, particularly to determine whether buckling of the cover plates would cause failure of the members under loads less than their estimated strength.

Two columns were, therefore, tested and it was found that the lateral deflection was very small until the stresses were

nearly the maximum. Under a stress of about 38,000 lb./in.^{2} the two cover plates began to buckle for their entire length. The results were in substantial agreement with the values obtained by the use of Bryan's formula for the compressive stress under which wide plates in ships may be expected to buckle. After these tests the chord members of the Kill van Kull Bridge were redesigned to eliminate the possibility of buckling of the cover plates.

A complete report of this work will be published as RP897 in the *Journal of Research* for June.

THE THIRD SPECTRUM OF XENON.

The third spectrum of xenon (Xe III) characteristic of doubly ionized xenon atoms (Xe^{++}) appears along with the second spectrum when a Geissler tube containing the gas is operated by an a. c. transformer with condensers and spark gap in the discharge circuit. The partial or complete suppression of lines originating in ions of higher stage than the first by the insertion of varying amounts of inductance in the discharge circuit has been used to distinguish the lines of Xe III from those of the other xenon spectra. An analysis of wave-length measurements of xenon spark spectra, based mainly on observations with the Bureau's Rowland grating and extending from 2200 to 8900A is given in RP898 in the June number of the *Journal of Research*. The majority of the Xe III lines are in the near ultraviolet region. About 300 lines have been classified arising from 84 levels of Xe III.

The low states of Xe^{++} are ^3P, ^1D, and ^1S, due to the $5s^2\ 5p^4$ configuration. The higher excited states are built upon the ^4S, ^2D, and ^2P states of Xe^{+++} by the addition of an ns, np, or nd electron to the normal $5s^2\ 5p^3$ configuration. Complete quantum number designations are given for about two-thirds of the levels. A sufficient number of levels are available to account for nearly all the terms belonging to the low and first excited states. Numerous instances of mutual perturbations between terms causing a sharing of combining properties makes an unambiguous assignment of quantum numbers difficult or impossible in such cases. These perturbations apparently are also responsible for frequent and

intense inter-system combinations as well as combinations between terms converging to different limits. The fact that all groups of terms are tied together permits an accurate calculation of their relative values. In all cases, permitted by the rules governing quantum transitions, the levels of first excited states combine with the low levels giving lines in the extreme ultraviolet region observed by J. C. Boyce. The absolute term values are arrived at from an estimation of the limit of the $5s^2\ 5p^3\ (^4S)nd\ ^5D^0$ series. The lowest $4s^2\ 4p^4\ ^3P_2$ levels comes out accordingly 259089 cm^{-1}, equivalent to an ionization potential of 32.0 volts for Xe^{++}.

TEXTILE FLAMEPROOFING.

The subject of fireproofing has been one of great interest since ancient times. It is said that the Romans attempted to fireproof their houses and war vessels by dipping the wood in a bath of vinegar and clay. Systematic research in the special field of textile flameproofing dates as far back as 1821, when Gay-Lussac published the results of an investigation suggested by Louis XVIII, in which he determined the flameproofness imparted by numerous chemicals when deposited on linen and hemp cloth.

Complete fireproofing of textiles—even making them fully resistant to charring and decomposition at high temperatures—has not yet been achieved, and is probably not possible. The most that can be expected of a flameproofed fabric is that it will resist ignition by a match or similar small source of heat, or that, if once ignited, it will not continue flaming upon removal of the source of ignition, since after a fire is well started, even a well-treated material will add fuel to the flame. Such flameproofing may be accomplished by impregnating the cloth with solutions of various chemicals, either singly or mixed.

These and other details of the history and principles of flameproofing are presented in the Bureau's new letter circular LC-467, "Flameproofing of Textiles," single copies of which are obtainable on request. The letter circular also includes an outline of the more important testing methods, a list of references, and formulas which have been recommended for making fabrics flameproof.

One of the formulas is that used in the Perkin process for cotton goods, in which water-insoluble stannic oxide is precipitated on and within the fibers by a chemical reaction between sodium stannate and ammonium sulphate. The cloth is first washed, then acidified with acetin or other weak organic acid, dried, and thoroughly saturated in a solution of 10.4 pounds of sodium stannate in 3 gallons of water, then squeezed and dried again. It is next run through a solution of 3.7 pounds of ammonium sulphate in 3 gallons of water, squeezed, dried, and washed in cold water. The goods should be heavily squeezed after passing through the solutions. This treatment is resistant to washing.

Another formula is that developed by Kling and Florentin of the Paris Municipal Laboratory, which specifies the use of 1½ pounds of borax and 1¼ pounds of boric acid in 3 gallons of water. This treatment is not resistant to the action of water. It has been much used for flameproofing interior decorations in public places such as theater stages.

STABILITY OF FILMSLIDES FOR RECORD PURPOSES.

The following summary of the Bureau's work during the past year on the stability of filmslides for record purposes was presented by B. W. Scribner, chief of the paper section, as part of a "microphotography round table" at the meeting of the American Library Association, in Richmond on May 12:

The study of the stability of motion picture films for record purposes now in progress at the Bureau, was undertaken as a natural extension of the work on the preservation of records written or printed on paper. Study of acetate films was initiated in June 1935 with the support of a fund allotted to the National Research Council by the Carnegie Foundation of New York. Later the National Archives also lent financial support to the undertaking, and because of the necessity for them to store nitrate films, the program was expanded to include this type.

To carry out these tests, new films of both types were secured from manufacturers, and old nitrate films were obtained from various depositories. It has not been possible as yet to obtain old acetate films.

In studying the films, conditions of extreme temperature and moisture are being used as accelerated aging tests, and the films are put through various cycles of temperature and humidity changes to find the optimum storage conditions. The tendency of the films to become brittle under such treatments is being studied by measuring the decrease in folding endurance. Chemical deterioration of the film base is being checked by determining whether any drop in viscosity of solutions made from the films, loss in weight, and increase in acidity occurs. In addition, the nitrate film is tested to determine the time required for acid fumes from the film to discolor a test paper on heating—a test used for gun cotton.

When new nitrate films were heated in dry air at 100° C., and reconditioned, which is the accelerated aging test used for paper, they became permanently brittle in 10 days, and evidence of extreme chemical deterioration was found. Under the same conditions, new acetate films retained good flexibility even after heating for 30 days, and showed little evidence of chemical change. On heating the films in an atmosphere of 95 per cent. relative humidity both types showed evidences of deterioration, although the nitrate films again were much less stable than the acetate. On putting the films through a cycle of various humidity conditions, it was found that the nitrate films retained their flexibility better than the acetate on loss of moisture, and showed less dimensional changes. The acetate films became quite brittle at low humidity, but their flexibility and approximately their original dimensions were restored on exposing them to a medium degree of humidity.

While the evidence is not yet complete, that already obtained shows that acetate films offer considerable promise for use as permanent records, if properly made and if care is taken to prevent them from drying out too much. They should be stored in air having a relative humidity of about 50 per cent. After they are used in the projection machine, they should be exposed to air of this humidity in such a way that the air has free access to all parts of the film, to restore moisture that may have been lost, and they should not be reused until moisture equilibrium has been obtained. This moisture condition plus a low temperature (not above about

50° F.) is suitable for prolonging the life of nitrate films. Such conditions have been recommended by the Society of Motion Picture Engineers' Committee on Preservation of Motion Picture Films.

Other problems such as the use of protective coatings, effect of aging on the emulsion, and conditioning of films for storage, are now being studied, but information on them is insufficient for a report at the present time.

THE FRANKLIN INSTITUTE.

RESOLUTION PASSED BY THE BOARD OF MANAGERS ON THE OCCASION OF THE DEATH OF DR. GEORGE A. HOADLEY.

The Board of Managers of The Franklin Institute record hereby their deep sense of loss in the death of their fellow member, Dr. George A. Hoadley, on May 18, 1936.

Born in Sheffield, Massachusetts, on December 2, 1848, the life span of somewhat over eighty-seven years which was vouchsafed to him covered unusually many years of active, helpful and distinguished services in the field of education and science.

He brought to The Franklin Institute the richness of his experience in teaching and administration in preparatory schools and in Swarthmore College, in which latter he was professor of physics from 1888 to 1914, and of which he was also a Vice-President.

A member of the Board of Managers since 1911, he served also as Acting Secretary of the Institute from 1917 to 1918, and again from 1924 to 1925. Elected as a member of the Committee on Science and the Arts in 1897, he acted as its temporary Secretary from 1921 to 1924. He was elected Secretary of that Committee in 1925 and continued active in most helpful and useful service almost until the day of his death.

His fine qualities and kindly disposition endeared him to all who had the pleasure of working with him.

Therefore, Be It Resolved that this expression of sorrow at the passing of so highly esteemed a member of the Board be spread upon its minutes, and that a copy be sent to Dr. Hoadley's family in testimony of the sympathy of the Board in their bereavement, and further that a copy be printed in the JOURNAL of the Institute.

June 17, 1936

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, June 10, 1936.)

HALL OF THE COMMITTEE,
PHILADELPHIA, JUNE 10, 1936.

MR. JOHN A. VOGLESON *in the Chair.*

The following reports were presented for final action:

No. 3011: Mechanical Grate for Gas Generators.

This report recommended the award of the Edward Longstreth Medal to Mr. John S. Haug, of Philadelphia, "In consideration of the invention and development of an improved type of mechanically clinkered water gas generator."

No. 3016: "Transitorq."

This report recommended the award of the Edward Longstreth Medal to Mr. Richard T. Erban, of New York City, "In consideration of the invention and development of the Transitorq, a practical and useful variable speed transmission unit."

CHARLES E. BONINE,
Acting Secretary.

LIBRARY NOTES.

RECENT ADDITIONS.

Beilsteins Handbuch der organischen Chemie. Vierte Auflage. Dreiundzwanzigster Band. 1936.

BERNEWITZ, M. W. VON. Handbook for Prospectors. Third Edition. 1935.

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DUGGAR, BENJAMIN M. Biological Effects of Radiation. Mechanism and Measurement of Radiation, Applications in Biology, Photochemical Reactions, Effects of Radiant Energy on Organisms and Organic Products. Volumes 1–2. First Edition. 1936.

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FOSTER, WILLIAM. The Romance of Chemistry. Second Edition, Revised and Enlarged. 1936.

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LOWY, ALEXANDER, AND BENJAMIN HARROW. An Introduction to Organic Chemistry. Fourth Edition. 1936.

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Mineral Industry, Its Statistics, Technology and Trade During 1932, 1933, 1934. Volumes 41–43. 1933–1935.

NEVINS, ALLAN. Abram S. Hewitt. With Some Account of Peter Cooper. 1935.

NORD, F. F., AND R. WEIDENHAGEN. Ergebnisse der Enzymforschung. 5 Band. 1936.

PLANCK, MAX. Philosophy of Physics. Translated by W. H. Johnston. 1936.

POOLE, E. G. C. Introduction to the Theory of Linear Differential Equations. 1936.

SCHOLES, SAMUEL R. Modern Glass Practice. No Date.

SPRATT, H. PHILIP. Libraries for Scientific Research in Europe and America. 1936.

TILDEN, SIR WILLIAM A. Chemical Discovery and Invention in the Twentieth Century. Revised by S. Glasstone. 1936.

WEIDLEIN, EDWARD R., AND WILLIAM A. HAMOR. Glances at Industrial Research During Walks and Talks in Mellon Institute. 1936.

WIEN, W., AND F. HARMS. Handbuch der Experimentalphysik. Band 16, 1 Teil. 1936.

BOOK REVIEWS.

THE ROMANCE OF CHEMISTRY, by William Foster, A.M., Ph.D. 497 pages, plates, 15 × 21.5 cms. New York, London, D. Appleton-Century Company, Inc., 1936. Price $3.00.

Chemistry has come to be of utmost importance in the world's work of providing for human utility and happiness. It has entered into every phase of life, and has become so commonplace in some that it is taken for granted. The growth of the science from ancient times was at first slow but gradually gained momentum until in the last century it has grown to such proportions and embodied so great a territory that it is now one of the basic sciences and has great cultural value. So vast is the subject and so spectacular its everyday accomplishments that its application is difficult to comprehend in its entirety. To write a book on the romance of chemistry is a stupendous task. The volume at hand is an admirable work in introducing to the layman the contributions of chemistry to mankind. It is the second edition, the first having been published less than ten years ago.

The author has chosen an unusually attractive style in presenting his work. First is presented the story of alchemy and the rise and development of chemistry, then, assuming no previous knowledge on the part of the reader, there is given simple instruction in the rudiments of the science. This is followed by descriptions of the applications of the science to topics of general interest and importance.

This is done in such a way that no reader, however non-technical, should fear being lost in a maze of complex technicalities. Each subject is discussed in a systematic manner in clear and simple language.

A large number of subjects are covered. They include industries dependent upon various chemicals such as soap making, the purification of water, sulphur, fertilizers, explosives, and carbon the producer of energy, etc. Chapters that may be classed as having particular appeal include the story of iron and steel, pottery and glass, dependence on chemistry by the farmer, the housewife, the physician, and the manufacturer. A new chapter added in this second edition is entitled "The Archæologists' Dependence on Chemistry." This chapter deals to a considerable extent with recent excavations at Corinth and at the Agora in Athens.

The book is illustrated with diagrams and photographs throughout, adding materially to understanding and inspiration. In the appendix there is a list of references, divided into the various chapters of the book. The subject index in the back should be very useful and it gives an idea of the great breadth of coverage in the book.

This book can be recommended to anyone as worthwhile. It is directed especially to the layman who cannot help but obtain a liberal knowledge of this great science. But the technical man can also derive much enjoyment and appreciation of many technical activities with which he may be only partly familiar. To all, it should provide inspiration to seek the truth.

R. H. OPPERMANN.

THE BOYS' BOOK OF MODEL AEROPLANES, by Francis A. Collins. 262 pages, plates, diagrams, 13 × 19.5 cms. New York, London, D. Appleton-Century Company, Inc., 1936. Price $2.00.

This is the third edition of a book that should delight the heart of every boy interested in aeronautics. Not only is it based on a fascinating story but it goes into sufficient practical theory to satisfy every boy as to the whys and wherefores of construction of various parts of the model aeroplane. Various designs are explained, selected beginners questions are answered, and curiosities of the air that affect the performance of a model are treated on. There are also rules for conducting model aeroplane contests, constitution and by-laws of a model aeroplane club, and a dictionary of aeronautical terms included.

The book is complete in every detail and is profusely illustrated with drawings and photographs. It is an invaluable how-to-do-it book for all devotees of model aeroplane building.

R. H. OPPERMANN.

THE CHEMISTRY OF NATURAL PRODUCTS RELATED TO PHENANTHRENE, by L. F. Fieser, Associate Professor of Chemistry, Harvard University. 358 pages, tables, illustrations, 15 × 23 cms. New York, Reinhold Publishing Corp., 1936. Price $6.50.

In one respect this book is remarkable, namely in the degree in which the literature has been covered even to the moment of going to press. Published on March 21st, the literature is reviewed to February 1st, 1936, with the exception of a few papers, some of which are referred to by notes. About 45 per cent. of

the references cited are to papers published within the period 1930–34, while the year 1935 alone accounts for no less than 23 per cent. of the total!

This field, of the utmost difficulty, is handled with great and perhaps deceptive simplicity. A bird's-eye view may be gained from the chapter headings: Chemistry of Phenanthrene and Some Instances of the Occurrence of Phenanthrene and Hydrophenanthrene Derivatives; Resin Acids; Cancer-Producing Hydrocarbons; Sterols and Bile Acids; Sex Hormones; Heart Poisons; and Saponins. These chapters are expanded by appropriate subgroups. Only an organic chemist could find a unity in such a diversity of material, and that but recently.

The bare listing of chapter titles and sub-titles carries but a poor impression of the richness of the material covered. Among the matters treated of more common knowledge are the phenanthrene alkaloids of which morphine is the principle member, two pages on drug addiction, and abietic acid and related compounds. Under the chapter on sterols and bile acids considerable material relative to vitamins may be found, cholesterol, ergosterol and zymosterol being the more prominent names. Advances in the field of sex hormones require nearly seventy pages and leave one gasping as to where we shall have come twenty years hence. The activities of bio-chemists may come to be seen as exerting forces in world affairs compared with which economic revolutions resulting from the activities of industrial chemists shall seem insignificant. The legendary poisonous principles of toad poisons of late years have been reduced to chemical formula.

This volume will excellently realize the author's purpose of consolidating the advances made and expediting further the development of the field of phenanthrene chemistry, of such enormous physiological importance. The point of view is that of the organic chemist rather than that of the medical practitioner although sufficient material on the physiological side is given to provide orientation. Many controversial aspects have been somewhat pushed into the background for the sake of simple exposition, a system having both recognized merits and demerits. Little space has been given to earlier literature which so often had to deal with compounds of questionable individuality.

This is the type of book which will be first seized upon by research men but it has the necessary substance to remain as a permanent contribution to a specialized field of organic and physiological chemistry.

LESLIE R. BACON.

SULFURIC ACID MANUFACTURE, by Andrew M. Fairlie. 669 pages, figures, 15 × 23 cms. New York, Reinhold Publishing Corp., 1936. Price $9.75.

The world's storehouse of knowledge is so full and its diffusion through the printed word so extensive that but rarely is it possible to bring out an idea or invention which has not been in some measure anticipated. New basic patents are few indeed and frequently they lead to infringement litigation in which a substantial defense often is the charge of invalidity due to "lack of invention." The sulfuric acid industry could supply a full quota of cases in support of the above theses. The chamber process in its essentials stands today as it did after the erection of the first Glover tower in 1859. The contact processes in principle are substantially unchanged after some 35 years of refinement, and the original catalytic process dates back to 1831. This volume, however, is studiously

directed to a description of sulfuric acid manufacture today with only enough of the historical development woven in to place developments in their logical relations. It concerns itself little with obsolete processes.

For many years the changes in processes have been dictated far more by changes in external economic conditions than by the discovery of new chemical principles. There have been many changes in practical details of course, in keeping with the development of new materials of construction and the capacity of fabricators to build equipment. All this is to be found at its proper place in the text. These changes in the aggregate occupy considerable space, which, together with the extended consideration of economic factors and trends in the industry account for the length of the book. It has no equivalent in English. Naturally it is the most up-to-date work of its scope although few references subsequent to 1932 are apparent. Some statistics as recent as 1934 are found. The aim has been to produce a volume sufficiently extended to be of genuine service in the industry but less cumbersome and minutely detailed than the venerable Lunge. Revision from time to time is contemplated.

Considerable attention is devoted to litigated cases, particularly to the catalyst patent situation. The author clearly has enjoyed the helpful coöperation of most of the larger manufacturers of acid and equipment as evidenced by the most excellent line drawings and photographs. Operating technique is discussed usually in the course of description of equipment.

The organization is somewhat rambling in character and perhaps equivalent material could be put in shorter space. Obviously Chapter XXII gathers up odds and ends but the relations between mixing and shipping sulfuric acid, hazards and safety measures, costs and cost accounting, to buy or to build, choice of process and trends in the industry, all of much importance to the whole, constitute a rather heterogeneous group. There is a good thirty-five page index and numerous acid tables in the appendices which also carry an extended table of general conversion factors. "Sulfuric Acid Manufacture" will prove extremely valuable to all concerned in any way with this industry.

LESLIE R. BACON.

THE ENGINE INDICATOR, ITS DESIGN, THEORY AND SPECIAL APPLICATIONS, by Kalman J. DeJuhasz. 243 pages, illustrations, 14 × 21 cms. New York, Instruments Publishing Company, 1934, price $3.75.

This book presents the history, theory and construction of the many forms of the pressure indicator from its inception to the present day. Most engineers are familiar with the steam engine indicator, indeed many have used them in conjunction with tests on the reciprocating engine either in school laboratories or in practical work. In modern work, however the principal of the indicator is being used in a widening sphere of applications in many diverse fields. For this reason the book is timely because of its theoretical and practical modern treatment.

Written in a clear and concise manner by a man who for many years has made the improvement of indicators his principal work, the book treats on the various makes of normal indicators, their general arrangement and component parts, high speed engine indicators, indicators for high pressures, maximum and mean pressure indicators, testing, calibrating and analytical theory of the indicator. Through all this there are pointed out advantages and disadvantages of various parts, the applications, and the actual operations of these indicators.

The book is profusely illustrated. An appendix contains Navy Department specifications for steam engine and internal combustion indicators. A bibliography is also appended of the more important books and bulletins in English, German and French treating in detail the indicator and its use.

It is a practical book. It should have wide usage. It is compact and the author has left no stone unturned to make it as helpful and interesting as possible. Every engineer having to do with forces and motions would do well to read this book and have it handy as reference.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS:

Report No. 553, Some Effects of Argon and Helium Upon Explosions of Carbon Monoxide and Oxygen, by Ernest F. Fiock and Carl H. Roeder, 10 pages, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

This investigation, performed at the National Bureau of Standards at the request and with the financial assistance of the National Advisory Committee for Aeronautics, is a study of the effects of the inert gases argon and helium upon flame speed and expansion ratio in exploding mixtures of CO, O_2, and H_2O. For the particular gas mixtures investigated the results show that (1) with the possible exception of He in small amounts the addition of inert gas always produces decreased flame speed and expansion ratio, (2) like volumes of A and He have very different effects upon flame speed but practically the same effect upon expansion ratio, and (3) the difference in the effect of these two gases upon flame speed is independent of the ratio of CO to O_2. A discussion of some possible modes by which inert gases may produce the observed effects is included.

Report No. 554. Wind-Tunnel Investigation of Ordinary and Split Flaps on Airfoils of Different Profile, by Carl J. Wenzinger. 14 pages, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

The Clark Y, the N.A.C.A. 23012, and the N.A.C.A. 23021 airfoils equipped with full-span ordinary flaps and with full-span simple flaps were tested in the N.A.C.A. 7- by 10-foot wind tunnel. The principal object of the tests was to determine the characteristics of the airfoils with ordinary flaps and, in addition, to determine the relative merits of the various airfoils when equipped with either ordinary flaps or with simple split flaps. The Clark Y airfoil was tested with three widths of ordinary flap, 10, 20, and 30 per cent. of the airfoil chord. The optimum width of the ordinary and the simple split flap based on the maximum lift attained with the Clark Y airfoil was then tested on each of the other two airfoils.

The optimum width of ordinary flap for maximum lift attainable was found to be the same as that of the split flap, 20 per cent. of the airfoil chord. The split flap produced somewhat greater increases in $C_{L_{max}}$ on the airfoils tested than did the ordinary flap of the same width, but the L/D at maximum lift was practically the same for the two types of flap. Any gap between the airfoil and the leading edge of ordinary flaps had a very detrimental effect on the $C_{L_{max}}$ attainable. Based principally on factors affecting airplane performance, the relative order of merit of the airfoils tested with either ordinary or split flaps is

N.A.C.A. 23012, Clark Y, and N.A.C.A. 23021. The hinge-moment coefficients (based on flap chord and area) of the full-span ordinary flaps were practically independent of flap chord; the actual hinge moments varied approximately as the square of the chord. In addition, the hinge-moment coefficients of the split flaps were practically the same as those of full-span ordinary flaps of corresponding widths.

Report No. 552, Wind-Tunnel Tests of 10-Foot-Diameter Autogiro Rotors, by John B. Wheatley and Carlton Bioletti. 14 pages, diagrams, 23 × 29 cms. Washington, Superintendent of Documents, 1936. Price ten cents.

A series of 10-foot-diameter autogiro rotor models were tested in the N.A.C.A. 20-foot wind tunnel. Four of the models differed only in the airfoil sections of the blades, the sections used being the N.A.C.A. 0012, 0018, 4412, and 4418. Three additional models employing the N.A.C.A. 0012 section were tested, in which a varying portion of the blade near the hub was replaced by a streamline tube with a chord of about one-fourth the blade chord.

With maximum L/D used as a criterion, the order of merit of the airfoil sections tested is: N.A.C.A. 4412, 0012, 4418, and 0018. The elimination of blade area near the hub was found to have a detrimental effect on the rotor L/D. The results indicate the possibility of obtaining further improvements in the L/D by using thinner airfoil sections and by employing tapered blades with a tip chord smaller than the root chord. The results also demonstrate the necessity for a study of the effect of blade twist on the rotor characteristics and show the advisability of improving testing technique to reduce the errors occurring in the determination of the tare drag.

R.

HOT SPRINGS OF THE YELLOWSTONE NATIONAL PARK, by E. T. Allen and Arthur L. Day. 525 pages, tables, illustrations, 23 × 29.5 cms. Washington, Carnegie Institution, 1935.

Anyone who has visited the Park will have been impressed with the phenomena of abundant springs and remarkable geysers. This rather weighty work of Allen and Day discusses the whole subject from many angles. The book is well illustrated with splendid photographs of basins, vents, cones, etc. It deals at length with the theory of hot springs, geysers and sub-volcanic manifestation that make the Yellowstone region so mysterious to the lay traveler and so very interesting to science.

Figure 1 shows Arnold Hague mounted on his pony's back from which position he must have directed much of the U. S. Geological Survey. The generous tribute to Hague and the other men associated with him is by way of happy introduction.

In reading this study I was taken back to the time when I dropped a handkerchief into a boiling spring to explain to the "dudes" that it had disappeared into the bowels of the earth. Presto-chango; up it came beautifully washed. Or again when we pitched camp just beyond Old Faithful hotel, slicked up our collars, slid into the hotel as guests, used letter paper for the benefit of folks back home. We did stand in admiration of Old Faithful's performance, then a bit longer than one hour between intervals. Frankly the reactions below ground did not interest

us then as much as the catching of trout in the teeming Yellowstone river or the simulation of bear after dusk for the benefit of tourists.

"Old Faithful looms large in any picture of the Yellowstone Park. . . . While many geysers in the Park may for one reason or another compete for our interest, there is after all none to compare with Old Faithful in beauty of its eruptions. . . . They begin with premonitory splashes which rise to a height of several feet, sometimes commencing 10 to 15 minutes before the time, but generally with shorter warning. Finally comes a higher splash, quickly followed by another and another, each rising with a muffled roar to a greater height before the others fall, until within a minute or two the peak is reached: a column of rushing water, draped with graceful lacy folds. One or two spurts may shoot up to a still greater height, until within three short minutes the column begins to fall in successive stages, reversing its rise. Like all geyser eruptions those of Old Faithful are considerably affected by wind and by condensation in cold weather. They are perhaps best seen in warm, dry days against a sunset sky."

Anyone who is seeking a thorough reference book on this subject will find this book worth reading and splendidly gathered—characteristic of the work of the authors.

H. W. ELKINTON.

PUBLICATIONS RECEIVED.

The Engine Indicator, Its Design, Theory and Special Applications, by Kalman J. DeJuhasz. 243 pages, illustrations, 14 × 21 cms. New York, Instruments Publishing Company, 1934. Price $3.75.

Cugle's Practical Navigation, by Charles H. Cugle. 546 pages, diagrams, 16 × 23.5 cms. New York, E. P. Dutton & Co., Inc., 1936. Price $7.00.

Down to Earth, An Introduction to Geology, by Carey Croneis and William C. Krumbein. 501 pages, illustrations, 17 × 23.5 cms. Chicago, University of Chicago Press. Price $3.75.

Der Aufbau der Zweistofflegierungen, Eine kritische Zusammenfassung, von M. Hansen. 1100 pages, illustrations, 16 × 23.5 cms. Berlin, Julius Springer, 1936. Price 87 Marks.

Elementary Principles in Physical Chemistry, by T. J. Webb. 344 pages, tables, illustrations, 15.5 × 23 cms. New York, London, D. Appleton-Century Company, 1936. Price $4.00.

Technologie Chimico-Textile Aide-Memoire de Chimie Industrielle et Technique, par Gustave Capron, 385 pages, tables, 14 × 22 cms. Paris, Les Editions Textile et Technique, n.d.

Canada Dominion Bureau of Statistics, Census of Industry, Food Products, Beverages, Rubber, Tobacco and Miscellaneous Manufactures Based on Vegetable Products, 1928–33. 176 pages, tables, 16.5 × 25 cms. Ottawa, King's Printer, 1936. Price 50 cents.

U. S. Coast and Geodetic Survey, Special Publication No. 198, First- and Second-Order Triangulation in Tennessee (1927 Datum), by H. P. Kaufman, 341 pages, maps, tables, 15 × 23.5 cms. Washington, Government Printing Office, 1935. Price 35 cents.

National Advisory Committee for Aeronautics, Aircraft Circulars, No. 203, The Vickers-Supermarine "Scapa" (British), A Military Flying Boat, 6 pages,

figures. Technical Notes, No. 566, Tank Tests of a Model of the NC Flying-Boat Hull—N. A. C. A. Model 44, by Joe W. Bell, 6 pages, tables, figures. No. 567, Tests of N. A. C. A. Airfoils in the Variable-Density Wind Tunnel. Series 230, by Eastman N. Jacobs and Robert M. Pinkerton, 5 pages, figures. No. 568. Calculated Effect of Various Types of Flap on Take-Off Over Obstacles, by J. W. Wetmore, 15 pages, tables, diagrams. Four pamphlets, 20 × 26 cms. Washington, Committee, 1936.

Iowa Engineering Experiment Station Bulletin 124, Effect of Nature of Filling Material and Dosing Cycle on Purification of Creamery Wastes, by Max Levine, G. H. Nelson and H. E. Goresline. 56 pages, tables, 15 × 23 cms. Ames, Iowa State College, 1935.

Canada Department of Mines, Petroleum Fuels in Canada, Deliveries for Consumption, Calendar Year 1934, prepared by John M. Casey, 20 pages, tables, 17 × 25 cms. Ottawa, King's printer, 1936. Price ten cents.

CURRENT TOPICS.

Shaky Dam Tied Down with Steel Cables.—(*Engineering News Record*, Vol. 116, No. 8.) A novel method of increasing the strength of a laterally weak masonry dam section was recently devised by A. COYNE in repairing dams at Fergoug and Cheurfas, Algeria. In the former case the crest section of the dam had been torn off by a flood and was to be replaced, and in the latter the operation was entirely a precautionary measure to prevent possible failure of a dam of insufficient cross section. The information of how it was done was taken from articles by Drouhin in *Annales des Ponts et Chaussees* and G. Barcelo in *Revista de Obras Publicas*. In both dams the method was to drill holes in the masonry from crest to deep foundation, insert steel cables in holes and seal them into the foundation, and then put the cables under great tension by a tightening anchor head bearing on the crest of the dam. In the Fergoug operation, the new crest of masonry was merely tied down to the old base masonry, but at Cheurfas the full masonry section was tied down to the ground strata.

R. H. O.

Zinc Sulphate for Apple Trees.—Although apples do not become zinc plated, the trees certainly are galvanized into action by treatment with zinc sulphate. *Better Fruit* for February 1936 tells how little leaf or apple rosette, a disease of apple trees, has been eliminated by injecting zinc sulphate into the trunks. Small holes, slanting downward, are drilled two or three inches into the tree. This keeps the zinc sulphate crystals from remaining near the tender cambium tissue just beneath the bark.

The holes are corked and heal over without injury to the tree. The zinc is gradually dissolved and taken up through the water-conducting vessels of the tree. Zinc-coated nails may be driven into the trunks or main branches for the control of this trouble.

The Seleggtor.—(*Factory Management and Maintenance*, 94, 68.) Seleggtor is the name given to a new machine that makes use of the photocell for candling and selecting eggs. It has a normal operating capacity of 12 to 15 cases per hour and combines one photoelectric grading with two visual inspections. After a preliminary "human-eye" examination the eggs are automatically transferred to a small conveyor, which advances them one by one

through a shutter-controlled beam of light where the photocell measures the proportion of firm white to yolk, thus "scoring" interior quality. Color of shell doesn't confuse the scoring as it does in visual candling.

The seleggtor grades eggs into four quality groups, and further divides top-grade eggs into large, medium and small sizes, each egg being deflected into one of six rows of rubber cup conveyors. This machine handles eggs so gently that checking or cracking of shells in less frequent than when ordinary hand candling methods are used.

C.

Alinco—A New, Powerful Magnet.—(*Power Plant Engineering*, Vol. XL, No. 2.) General Electric Company announces this new alloy, which is expected to open up new fields of application. Only a few years ago an alloy of iron, aluminum, and nickel was discovered to possess suitable permanent magnet properties. This alloy contains no carbon and belongs to the precipitation hardening type of alloys, quite distinct from steel. The addition of cobalt was the next step; and thus was born Alinco. With the discovery that a precipitation hardening alloy may possess excellent permanent magnet properties, an entirely new field of alloys for magnets was opened. Alinco is usually a cast material, finished to shape by grinding. The coercive force is higher and the residual induction lower for Alinco than for other magnetic materials. The maximum available energy is higher and occurs at a lower flux density and a higher demagnetising force. Alinco magnets may, therefore be of smaller volume but generally should be designed with greater cross sectional area and shorter length to maintain a given magnetic field in an external air gap. They are less subject to demagnetization by stray fields, by high temperatures and by mechanical vibration. Vibration tests on Alinco bar magnets resulted in a decrease of less than one per cent. in a total flux after severe vibration at 120 cycles per second for one half hour. Alinco magnets require a magnetizing force of at least 2,000 oersteds (4,040 ampere turns per inch) to magnetize them. The new alloy has a relatively low specific gravity (6.9), is non-corrosive, and is brittle.

R. H. O.

Fog For Movies Made to Order.—(*Compressed Air Magazine*, Vol. 41, No. 2.) Artificial fog for moving pictures used to be made from a combination of smoke and ammonia gases. While it was satisfactory in itself, it caused eyes to smart and throats to ache. Aside from the discomfort, it interfered with production, as the

players sometimes experienced difficulty in properly portraying the desired emotions. The studios of Samuel Goldwyn Inc., Ltd., now have an official fog maker who has become so adept that he can control the height and density of a fog within a few feet. Ordinary mineral oil is used. About 3 gallons of it is put into a steel tank, approximately 18 inches in diameter and 18 inches high, in which is a smaller steel container holding a cake of ice. When brought in contact with high-pressure air, the chilled oil gives off a vapor that is much like fog of nature's making. Compressed air at 110 lbs. is applied into the tank through a jet inserted in the side. Because of the noise, the paraphernalia is enclosed in a cabinet, the fog issuing thence by way of long hose connections. By heating the oil vapor to just the right degree, a London fog can be produced, rising only a short distance above the ground. To simulate an all-prevading San Francisco fog, the vapor must be raised to a high temperature in order that it may reach well above the set. The use of oil, however, is sometimes prohibited, as when it comes in contact with costly furniture. It is then that ordinary Chinese incense is burned. While unpleasant from the perfumers' standpoint, it is more satisfactory for this purpose.

R. H. O.

Fifty Tons at One Scoop.—(*Power Plant Engineering*, Vol. XL, No. 3.) With the ability to pick up a 50 ton load and place it on top of an ordinary six or seven story office building, a power shovel has recently been placed in operation by the Northern Illinois Coal Corporation for use in coal stripping service. One of the outstanding features of this giant is its immense dipper, or bucket, which has a rated capacity of 32 cubic yards. The dipper is fabricated from aluminum plates and castings with an armor of special wear-resisting steel at points of greatest wear. The machine has electric drive and control equipment, in fact it constitutes a large power plant in itself, the equivalent ratings of all the motors and generators on the shovel totaling more than 3,500 hp. With the system of voltage control used, slight pressure of the operator's hands on master switch handles produces working pressures of several hundred thousand pounds at the dipper teeth. It is interesting to speculate upon the possibilities of this machine. Suppose that it could be used to fill the storage hoppers of a large power plant. Assuming this shovel to operate 10 hr. a day, it would handle 900,000 tons of coal a month. Operating at this rate it would handle the entire coal supply for a power plant having an installed capacity of three million kilowatts operating at 80 per cent. load factor.

R. H. O.

Inerteen Power Capacitors.—R. E. MARBURY (*Electric Journal*, Vol. 33, No. 2.) The demand for large capacitors for power factor improvement on alternating-current systems has resulted in a continuous advance in their construction during the past 15 years. Oil capacitors have now been developed to a point where little improvement can be made in size, weight and cost. They give highly satisfactory performance but do have two limitations: their performance at very low and very high temperatures and the inflamability factor. A new type, known as the Inerteen Capacitor has recently been developed. Its construction is similar to the oil unit. Inerteen is a new synthetic liquid possessing properties that make it ideal for power capacitors. It does not support combustion and does not freeze or crystalize at any temperatures encountered. It is a pale yellow viscous liquid at room temperature, having a specific gravity of 1.55 and a resistivity of 3×10^{12} ohms per cubic centimeter. It is non-drying, non-corrosive, soluble in almost all the organic solvents and insoluble in water. There is little difference between the losses, or per cent. power factor between oil and Inerteen. The performance of Inerteen Capacitors under very low temperatures even to the point where the liquid becomes solid, as well as under high temperatures far beyond those encountered in service, is exceptionally good. Excessive currents due to harmonics do not harm an Inerteen Capacitor if they are within reasonable limits. When such unusual conditions occur, they usually require some corrective measures.

R. H. O.

North Atlantic Coast Fights New Marine Borer Attack.—DR. WM. F. CLAPP. (*Railway Age*, Vol. 100, No. 8.) An intensive study of marine borer activity ended a little more than 10 years ago. Test boards placed along the New England coast showed little or no borer activity, consequently investigation ceased in this section. In 1933 the author discovered a sudden and exceptionally severe attack by *Teredo navalis* in Plymouth harbor. It resulted in the destruction of all the wharves in this harbor in two years time. Early in 1934, a committee was formed of representatives from most of the New England railroads and from some of the state departments of public works to make a study. Approximately 100 test boards were placed in harbors from Eastport, Me., south to the New York state line. The increase in attack by marine borers in the New England waters is so alarming that the investigation is to be continued and its scope enlarged during 1936. *Teredo navalis* have invaded the Cape Cod Canal, Manomet, Scituate, Hull and Neponset, Mass. In Boston, large living

specimens are to be found in practically every structure throughout the entire open harbor. The *Limnoria lignorum* are also widespread along practically the entire New England coast. The attack is new and excessive, and in places is as severe as has been recorded at any place in the world, not excepting Bermuda and the tropics. Other borers are also noted. The reason for all this has not yet been explained satisfactorily. Among the factors which are considered as having some bearing on the distribution of these borers are temperature, salinity, acidity, free oxygen, sulphuretted hydrogen, nitrates, nitrites, and pollution. The last mentioned factor includes not only sewage, but also industrial waste, oil, catch-basin overflow, Tarvia from the roads, etc.

R. H. O.

Marble Windows.—(*Business Week*, Mar. 21, 1936.) A fresh shock for those who haven't got used to glass as a wall material is on the way—marble can be used for windows. You can't see through it, but window panels comparable to stained glass are now available. This is one of the possibilities of Lumar, a new type of marble which has been developed by the Vermont Marble Co. and the Mellon Institute of Industrial Research. The Lumar method takes advantage of the crystalline make-up of marble, by selecting and cutting it in such a fashion that interior luminosities may be displayed. If daylight isn't available for the lighting source, ordinary electric bulbs of moderate wattage will do. Various thicknesses of the marble lead to various degrees of translucence, so that the user may suit his own taste in the quantity of diffused light which comes through the panel. It is expected that the stone will be fitted to a wide range of uses, from lighting fixtures to entire walls, and for novelty effects such as may be had by using it in radio cabinets of other articles which have lighted interiors.

R. H. O.

A New Gas Calorimeter.—RAFAEL W. KEITH. (*Mechanical Engineering*, Vol. 58, No. 4.) This paper is a report of research conducted in the laboratories of Cornell University. The instrument is based on the principle of thermal balance, which differs radically from that customarily used in calorimeter design. Instead of obtaining the measurement of the heating value of a gaseous fuel by the weight and temperature rise of a fluid of known specific heat, a standard source of heat is used and two temperatures are matched in separate sections of a current of air. Practically, two thermally insulated chambers are involved, a primary chamber where the fuel to be tested is consumed in a burner, and a secondary chamber where

a standard source of heat is placed. The latter may be either an electric heater, or a burner consuming gas of known heating value. The choice between the two depends chiefly on the application of the calorimeter. The working substance, which consists almost entirely of room air, is drawn through the calorimeter by means of a small suction blower. The fluid first enters one leg of a heat exchanger where it is slightly increased in temperature. It then goes through the primary chamber and is warmed further by the combustion of the test gas. About 500 volumes of air flow through the primary chamber for every volume of test gas consumed in the burner. The fluid leaving the primary chamber is then admitted to another leg of the heat exchanger and is cooled to a temperature close to that prevailing at the inlet of the primary chamber. It is then sent through the secondary chamber and its temperature is again increased by the standard source of heat located in that chamber. The respective outlets of the combustion chambers are equipped with two bulbs of a differential thermometric device that reads zero if the two chamber outlet temperatures are the same; but if this quality is lost, the pointer will move to the right or left, depending on which chamber is warmer.

R. H. O.

The Superposition Turbine.—N. D. GOVE. (*Electric Journal*, Vol. 33, No. 3.) Recent literature on turbines has contained descriptions of the superposition turbine which, by taking steam at high temperature and exhausting into existing low pressure turbines, makes available the economies of high pressure and high temperature operation. A new superposition turbine has been developed for plants whose low pressure units are not equipped for bleeding. It has an additional element from which steam can be extracted for feedwater heating without loss of energy in the steam. A typical superposition feed heating arrangement uses two turbines in tandem. The high pressure turbine by itself is of the customary superposition type exhausting into an existing boiler system at constant back pressure or into one or more low pressure turbines with variable cross over pressure. Since the existing low pressure turbine is not equipped with bleeder openings, the feed water would have to be heated partly by auxiliary exhaust steam and the remainder by steam taken from a cross over pipe. In a modern plant there is seldom much auxiliary exhaust steam. A large quantity of steam would have to be taken from the cross over pipe to heat the feedwater, and no additional power would be extracted from this steam. To make available by-product power from this steam a large proportion of it is passed through a low pressure turbine and taken out at suitable

points for feedwater heating. The low pressure or feed heating turbine is in tandem with the superposition element so that no additional generators with their control are necessary. The low pressure element of the superposition turbine may increase the output of the generator 6.5 per cent., which means this much by-product power is obtained in this expansion of steam for feed heating.

R. H. O.

Conversion on Springs.—A. M. GOODISON in *Power*, Vol. 80, No. 4, describes an unusual installation at the Safe Harbor Water Power Plant of a frequency changer set. The set supplies power to the Pennsylvania Railroad and consists of a generator rated at 31,250 kva., single phase, 13,300 v., 25 cycles, 300 r.p.m. and a motor rated at 29,700 kva., 3 phase, 60 cycles, 13,800 v. The motor frame rests in a cradle supported by the foundation. The loose frame feet, mounted on the bedplate, act as guides at the point normally occupied by stationary frame feet. Bearing surfaces of the cradle and feet are adequately lubricated. There is a frame shifting device containing two cylinders, one on each side of the machine's center line, with a common plunger attached at its center to the machine frame by links. Horizontal movement of the plunger is transmitted to rotational movement of the frame through these links. Plunger movement is controlled by admitting oil under high pressure to the cylinders. To prevent transmitting the pulsating torque, characteristic of a single phase machine, to the foundation and building structure the generator frame is supported on a spring system. It consists of a number of flat springs spaced and supported on fulcrums to provide free vertical spring action. A high strength spring steel is used, similar to that in locomotive springs. The system is so designed that with the frame static load and torque equivalent to full load, the springs will not deflect sufficiently to permit spacer blocks to contact. In the event of short circuit the springs deflect to the extent that the blocks attached to the frame and foot will contact loose members in the assembly thereby bringing the springs into action for both directions of torque pulsations.

R. H. O.

Turbine Turning Gears.—The April 1936 number of *Electric Light and Power* contains an article by P. W. THOMPSON, condensed from the Detroit Edison Co.'s organ "Synchroscope" describing such a device for turning the shaft of a steam turbine at a slow speed during shutdown periods to prevent warping or bowing of certain

parts due to stored heat. This permits setting the clearances between stationary and movable parts to a few thousandths of an inch and enables the operator to start the turbine without interference between its internal parts. The device consists of a motor driven train of gears in a casing mounted on the cap of the bearing housing between the turbine and generator. Rotation of the shaft at a speed of one and a half revolutions per minute is effected through engaging, by means of a hand operated lever, the driving gear with the large spur gear on the main shaft coupling. The train of driving gears is so arranged that when steam is admitted to the turbine, thereby increasing its speed of rotation, the driving gear will automatically be disengaged from the gear on the coupling. The advantage obtained in improving the economy through setting the internal clearances closer than would have been safe had no turning gear been used was greater than had been predicted. Carefully conducted tests show that the average steam rate improvement on five of the 50,000 kw. turbines at Trenton Channel Station is 2.4 per cent. This means a proportionate reduction in the amount of coal required to produce one Kwh.

R. H. O.

Cathedral Completion Advances.—(*Stone*, Vol. LVII, No. 3.) Not many people outside of the New York area know that the Cathedral of St. John the Divine on Morningside Heights, New York City, has been under construction for the past four decades. It was proposed in 1872 by the late Bishop Horatio Potter. The Close was purchased in 1891 and the first services on the grounds were held a year later. The corner-stone was laid December 27, 1892, and the parts thus far built are the Crypt, Choir, Seven Chapels of Tongues, and the Baptistry. To date more than $14,000,000 have been expended and work has been given to several thousand men. It is estimated that an additional $10,000,000 will be required to complete the structure. To visitors something of the immensity of the cathedral is more in evidence now than at any time in the past. It will be the greatest structure of its kind in the English-speaking world and will be among the most imposing ecclesiastical buildings ever erected. In area it will be twice the size of St. Paul's in London and 45 feet longer than Winchester Cathedral. In architectural beauty it will rank with the cathedrals of Seville, Milan and Bourges. The tip of its cross atop its towering spire will be 631 feet above tidewater. There are eight great piers of Buff Indiana Limestone and eight lesser piers of Sommes Sound Granite. There will be standing room for 40,000 people. As a

work of masonry the cathedral is an object lesson in combined modern and ancient methods.

R. H. O.

Man-Made Microseismic Disturbances.—Engineers of the Bureau of Public Roads have developed practical field methods for determining the distance below the ground surface to solid rock. The measuring instrument is a highly sensitive electrical device known as a seismograph. Through this instrument's ability to time precisely sound waves racing through earth and through earth and rock engineers can estimate to within a few feet how far below the surface rock will be found and thus save the time and expense of drilling.

Accurate results are obtained by measuring the speed with which an impulse from the explosion of a buried blasting cap or small charge of dynamite travels through the ground. Such an impulse will travel through soil at a speed of 1,000 to 6,000 feet per second but the speed through rock is 16,000 to 20,000 feet per second. A cap is exploded in the ground and at the same time the electric current exploding the cap causes a record to be made with precise apparatus for measuring time. Special detectors are placed at different distances from the explosion and pick up the impulse as it comes through the ground.

When a detector is close to the explosion one impulse coming through the soil is received. At a greater distance an impulse coming through soil is received and a second one moving down through soil to rock, through rock, and from the rock up to the surface arrives a fraction of a second later. At still greater distances the impulse moving through soil and rock arrives ahead of the impulse moving more slowly through soil alone. Knowing the speed of travel through soil and through rock and the time of travel through different distances it is possible to calculate how far the impulse went downward through soil before it encountered rock.

This method, involving elaborate and costly apparatus, has been used extensively in prospecting at considerable depth for oil. The Bureau of Public Roads has now developed simplified apparatus that is giving excellent results.

C.

Earthworms and 6500 Å.—Earthworms cannot "see" red although one hardly could blame them if they did considering the treatment many of them receive. W. R. WALTON (relation to Isaac unknown) of the Bureau of Entomology and Plant Quarantine,

suggests that fisherman, when hunting worms at night, use a red light since the annelids apparently are insensitive to this section of the spectrum. Flashing an ordinary light on the worms as they emerge from their burrows causes them to retreat quickly. They also slide back into their holes when a blue light strikes them. Although the worms do not have eyes, the forward parts of their bodies appear to possess the greatest sensitiveness to light.

C.

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